

MUREX

WELDING GUIDE



MUREX (AUSTRALASIA) PTY. LTD.

MUREX

WELDING

IS

OUR

BUSINESS

Our business is welding, and we offer this handbook to both the welder and industry in general in an earnest endeavour to assist all those engaged in electric arc welding to a greater knowledge of the subject.

We have not tried to cover all phases of welding, but to present the pertinent factors necessary to assist the welder to a better understanding of the materials and techniques found in industry.

We also offer you the services and facilities of our technical representative and research team who are readily available to give advice on your welding problems.

We invite you to avail yourself of these facilities at all times.

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DEFINITION OF ARC WELDING TERMS

Arc Voltage: The voltage across the welding arc.

Arc Blow: This is peculiar to D.C. The arc, instead of playing steadily on one spot, is deflected away from point of welding by influence of surrounding magnetic fields.

Backing Strip: Material (metal, carbon, asbestos, etc.) backing up a joint during welding to help obtain a sound weld. (See Fig. 1.)

Basis Metal: The metal to be welded.

Cold Crack: Crack occurring in weld metal or in the heat-affected zone of the basis metal after cooling.

Concave Fillet: Fillet weld having concave face. (See Fig. 2.)

Convex Fillet: Fillet weld having convex face. (See Fig. 3.)

Crater: Depression at the termination of weld bead.

Crater Crack: Crack in weld bead crater.

Depth of Fusion: Distance that fusion extends into basis metal. (See Fig. 5.)

Earth (or Ground) Lead: See Work Lead.

Electrode Lead: Conductor between source of current and electrode holder.

Flux: Fusible material coated on to electrodes for removal of oxides and other impurities. (See section, "The Welding Electrode.") **P 12**

Fusion: The melting together of filler metal and basis metal, resulting in coalescence.

Ground Lead: See Work Lead.

Haloes or "Fish-eyes": Small, shiny, circular areas displayed on the surface of weld metal after fracture by a tensile stress.

Hardfacing: The process of covering wearing areas with wear-resistant metal by welding.

Hard Zone Crack: See Underbead Crack.

Heat-affected Zone: The region beneath the weld bead which has not melted, but whose mechanical properties or micro-structure has been altered by the heat of welding. (See Fig. 5.)

Hot Crack: Crack occurring in weld metal soon after solidification commences.

Intermittent Welding: Welding wherein continuity is broken by recurring unwelded spaces. (See Figs. 15 and 16.)

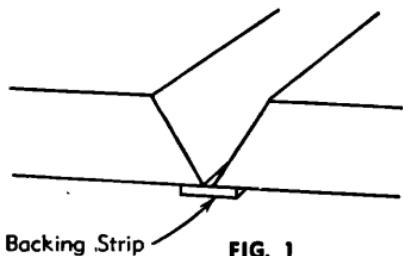


FIG. 1

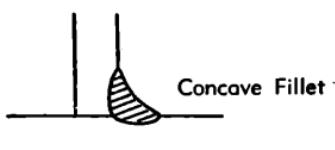


FIG. 2

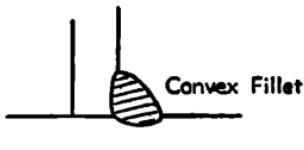


FIG. 3

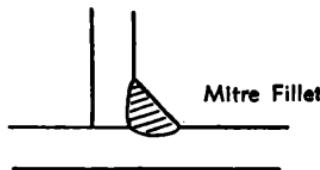


FIG. 4

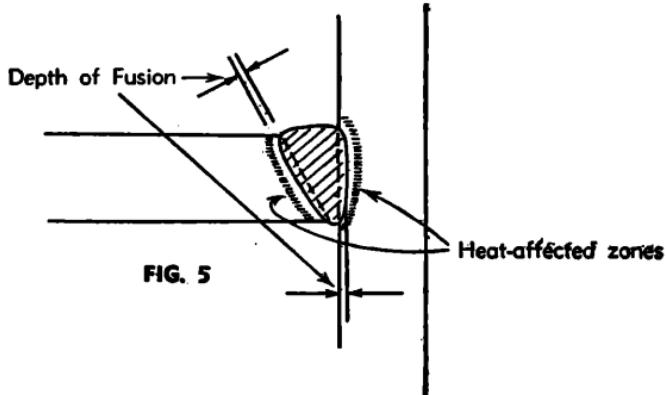


FIG. 5

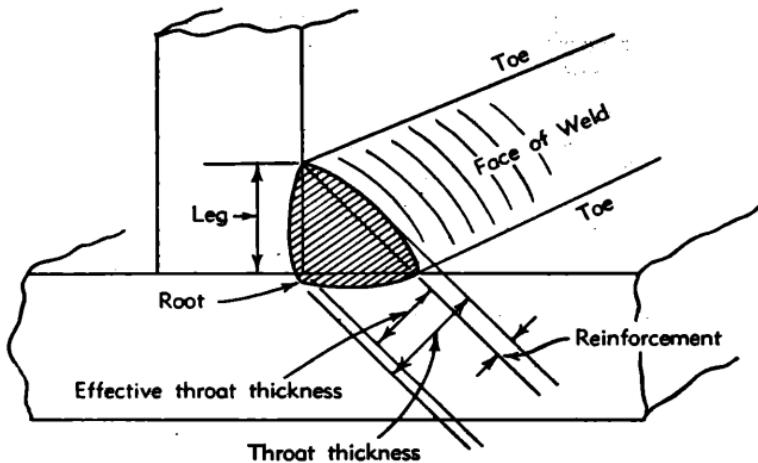


FIG. 6

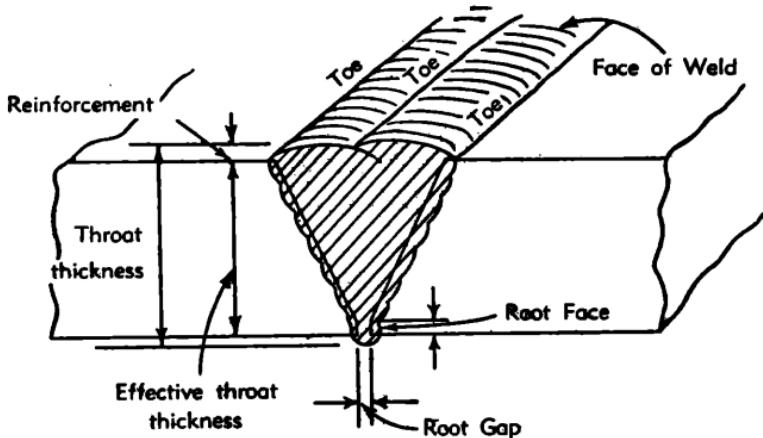


FIG. 7

Interpass Temperature: In a multiple weld, the lowest temperature of deposited metal before the next pass is started.

Lack of Fusion: A weld fault wherein adequate fusion of weld and basis metal is not obtained. (See Fig. 60, p. 35.)

Leg of Fillet Weld: Distance from root of joint to toe of fillet weld. (See Fig. 6.)

Mitre Fillet: Fillet weld in which the face of the weld is approximately flat. (See Fig. 4.)

Open-circuit voltage: Voltage between terminals of power source when no current is flowing.

Overlap: Protrusion of weld metal beyond bond at toe of weld.

Parent Metal: Same as basis metal.

Pass: A single welding run along a joint or weld deposit. The result of a pass is a weld bead.

Peening: The mechanical working of metals by relatively light hammering.

Penetration: The depth a weld extends into a joint from basis metal surface. (See Fig. 8.)

Porosity: Gas pockets or voids in metal.

Post-heating: Application of heat to the weldment after welding is completed.

Preheating: Application of heat to the basis metal before welding commences.

Reinforcement of Weld: Weld metal lying outside the plane joining the toes of a weld. (See Fig. 6.)

Reverse Polarity: Arrangement of D.C. arc welding leads wherein the work is the negative pole and the electrode is the positive pole of the welding arc.

Root of Weld: The zone on the side of the first run farthest from the welder. (See Figs. 6 and 7.)

PENETRATION

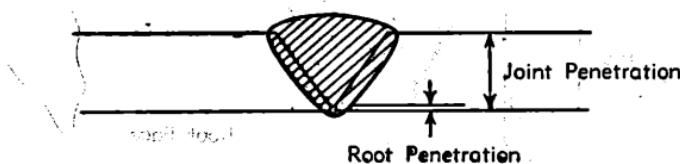


FIG. 8

DEEP PENETRATION

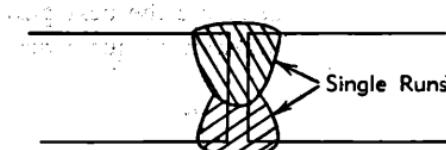


FIG. 9

BUILD UP SEQUENCE

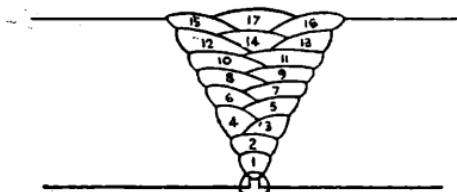


FIG. 10

BLOCK SEQUENCE

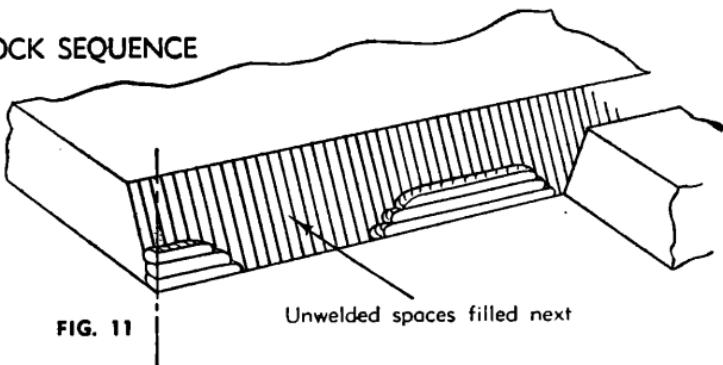


FIG. 11

CASCADE SEQUENCE

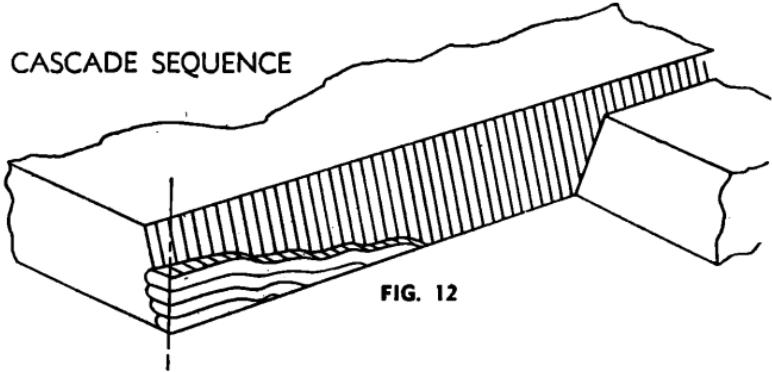


FIG. 12

Root Face: The unbevelled or ungrooved portion of a fusion face at the root. (See Fig. 7.)

Slag Inclusion: Non-metallic solid material trapped in weld metal or between weld and basis metal.

Spatter: Metal particles expelled during welding which do not form part of the weld.

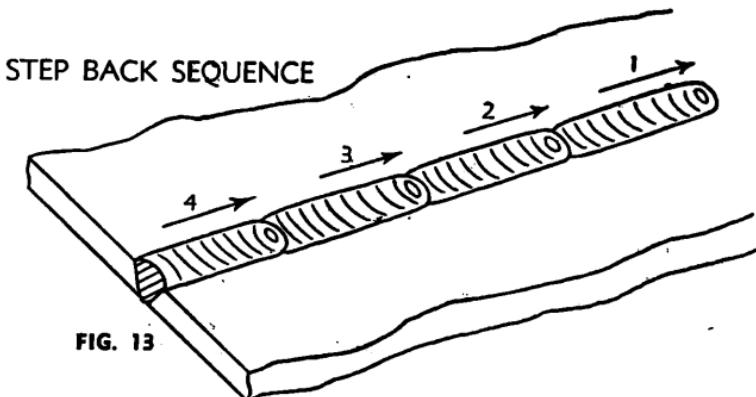


FIG. 13

BALANCED SEQUENCE

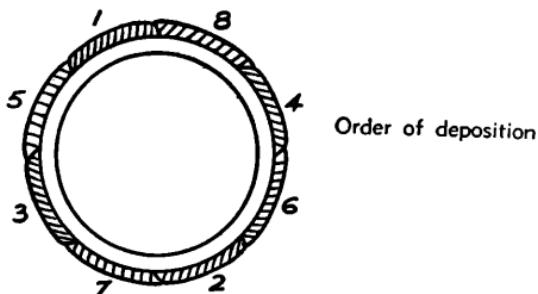


FIG. 14

Straight Polarity: Arrangement of D.C. arc welding leads wherein the work is the positive pole and the electrode is the negative pole of the welding arc.

Tack Weld: Small weld made to hold parts in proper alignment until final welds are made. (See Fig. 45, p. 27.)

Throat Thickness (see Figs. 6 and 7): The minimum thickness of weld metal in:

- Fillet weld, measured along a line passing through the root.
- Close square butt joint, measured in the plane of abutting faces.
- Open square butt weld, measured in centre of original gap parallel to fusion faces.

Effective Throat Thickness: Dimension arbitrarily adopted as throat thickness for design purposes.

Toe: Boundary between weld face and parent metal or between weld faces. (See Figs. 6 and 7.)

Underbead or Hard Zone Crack: Crack in the heat-affected zone which may or may not extend to surface of basis metal. (See Fig. 72, p. 47.)

Undercut: A groove melted in the base metal adjacent to the toe of a weld, and left unfilled by weld metal. (See Figs. 54 and 55, p. 32.)

Weave Bead: Weld bead made with slow oscillating motion of the electrode.

Welding Sequence: The order of making welds in a weldment. (See Figs. 10-14.)

Work Lead: Conductor between source of current and work or work table.

Work Piece: The job or component being welded.

CHAIN INTERMITTENT WELDING

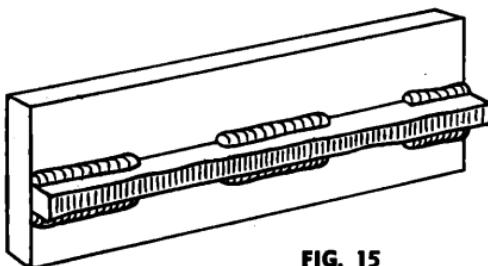


FIG. 15

STAGGERED INTERMITTENT WELDING

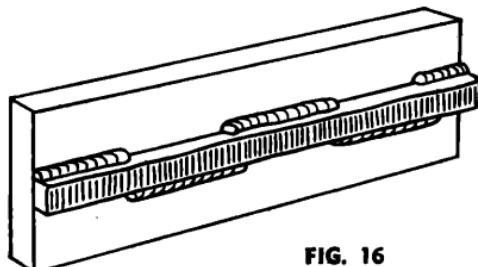


FIG. 16

ARC WELDING— THE PROCESS

FUSION WELDING is really a melting and casting process in miniature, the various components of the welding process (basis metal, weld metal, slag, etc.) forming the crucible and contents of a tiny electric furnace.

The electric arc, with a temperature of the order of 6,000 deg. C., is a concentrated and efficient source of heat. The electrode and parent metal, acting as poles of the arc, utilise this heat, the core wire melting and being transferred across the arc to coalesce with the molten parent metal and form a bond, which, in many cases, is stronger than the parent metal.

The weld metal itself, as deposited, has a cast structure. Its composition is determined by the core wire and coating of the electrode, and by the amount of pick-up of parent metal during welding. For example, a deposit of alloy steel, say, stainless steel, on mild steel, no longer has just the properties expected of that alloy, due to dilution with the parent metal. This kind of thing, in many cases, is not important, but, if desired, it may be eliminated by using multi-layer welds.

Welding on materials that have been strengthened by heat-treatment or cold-working generally creates a zone of lower strength along the weld boundary. This may not affect the serviceability of the welded joint, but sometimes it is necessary to restore this strength by further heat-treatment or cold-work.

ADVANTAGES OF WELDING:

Some of the advantages that welding has over riveting and casting methods of assembly are as follows:

1. Welding is usually a cheaper process than riveting for any particular joint, and the joint can often be made much more quickly.

2. It gives a stronger joint and permits the use of less material, thus reducing the weight and cost of the structure.
3. Welded seams are normally pressure tight, and do not need caulking as do riveted joints. Joints are smooth, which is important in many applications. For example, painting is much easier on welded joints, and turbulence in pipes is reduced.
4. Designs not practicable for riveting may be constructed by welding.
5. Plate preparation for welding is generally cheaper than for riveting.
6. Labour necessary can often be cut to less than one-third of that necessary for riveting.
7. Welding is not as noisy as riveting, and permits building and alterations to proceed with the least disturbance to occupants.
8. Welding is more versatile than casting; changes in design can be made quickly without having to produce a new pattern.
9. Rolled section is often cheaper than cast section, and fabrication by welding of rolled section may be cheaper than casting the same article.
10. No storage of patterns is necessary for welding, as with castings.
11. Articles of consistent and known quality can be produced by welding, whereas castings may have external or hidden internal flaws causing their rejection, or failure in service.

THE WELDING ELECTRODE

THE COATING on arc welding electrodes serves a number of purposes:

1. To provide a gaseous shield for the weld metal, and preserve it from contamination by the atmosphere whilst in a molten state.
2. To give a steady arc by having "arc stabilisers" present, which provide a bridge for current to flow across.
3. To remove oxygen from the weld metal with "deoxidizers."
4. To provide a cleansing action on the work piece and a protective slag cover over the weld metal to prevent the formation of oxides while the metal is solidifying. The slag also helps to produce a bead of the desired contour.
5. To introduce alloys into the weld deposits in special type electrodes, e.g., Austex and the Hardex series, which have mild steel core wire, but contain alloys in the coating.

STORAGE OF ELECTRODES:

Electrodes not stored in a dry place will absorb moisture from the atmosphere. Dampness in electrodes may have some of the following effects:

1. Fiery arc.
2. Excessive spatter.
3. Porosity in weld metal.
4. Spalling of flux coating.
5. Blistering of electrode tip.
6. High arc voltage.
7. Introduction of hydrogen into the weld metal, with increased danger of hard zone cracking on hardenable steels.
8. Formation of white "fur" on flux coating. In most cases this does not have any deleterious effect.

Electrodes are best stored in a room or cupboard where a constant, warm temperature is maintained. This may be achieved simply by having a small cupboard in which two 60 watt bulbs are burning constantly.

Electrodes which have become damp may be dried out by heating at 110 deg. C. for 10 minutes. Low-hydrogen type electrodes should always be dried just before use by heating to at least 150 deg C. for 30 minutes.

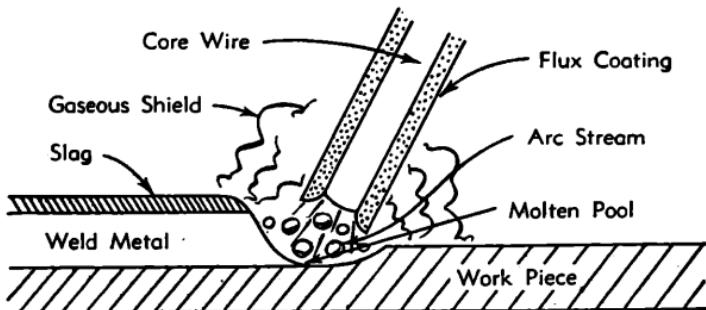


FIG. 17 THE WELDING ELECTRODE

THE WELDING CURRENT

BOTH DIRECT and alternating currents may be used for arc welding. In Australia, most work on mild steel is done using A.C.

A.C. welding machines have several advantages over D.C. machines, among them being a lower purchase cost, higher operating efficiency and negligible maintenance. The quality of welds produced using A.C. is equally as good as when D.C. is used. However, A.C. is limited in that it will not satisfactorily run many of the non-ferrous types of electrodes.

The open-circuit voltage of an A.C. machine is important, because some electrodes need a fairly high voltage to prevent the arc cutting out during welding. The open-circuit voltage depends on the design of the machine.

The tendency for the arc to cut out may also be eliminated by impressing a high frequency current on the welding circuit. The latter method, however, may cause radio interference.

The question of open-circuit voltage is not so important with D.C. machines, since there is not the constant reversal of current necessitating continual re-establishment of the arc.

When using A.C. it does not matter to which terminal the electrodes and the work piece are attached, but when D.C. is used more heat is produced at the positive pole with most electrode types and the manufacturer's recommendations for the most suitable polarity should be followed. With the welding of mild steels, although either polarity can be employed, it is usual for the work piece to be made the positive pole. The greater amount of heat generated at the work piece in this way assists the welding operation, especially when the components have a heavy mass. Proper fusion and good penetration are assured in this way. If on the other hand the electrode is connected to the positive pole, the greater heat

generated at the electrode tip results in a faster burn-off rate and the electrode is deposited more quickly. This increase in deposition rate, however, may not amount to more than 5 per cent. and the advantage gained in this way is offset by the reduction in depth of penetration obtained with the resulting weld deposit. The burn-off rate with A.C. supply is approximately the same as for D.C. supply with the electrode connected to the negative pole.

With some special electrodes having a very thick coating such as the Deepex type, opposite arc conditions are present and the electrodes should be connected to the positive terminal to obtain the highest penetration with the weld deposits. Most of the non-ferrous and stainless steel electrodes should be connected to the positive terminal, but this is recommended because of the greater arc stability obtained.

ARC BLOW:

This is peculiar to D.C. The arc, instead of playing steadily on one spot, is deflected away from the point of welding due to the influence of surrounding magnetic fields created by welding currents flowing in the work. It may often be overcome or minimised by shifting the earth clamp to another part of the work piece.

RECOMMENDED CURRENT RANGES FOR STANDARD MILD STEEL TYPES OF ELECTRODES

Gauge	16	<u>14</u>	<u>12</u>	<u>10</u>	<u>8</u>
Amperes	20-30	<u>45-70</u>	<u>65-100</u>	<u>100-140</u>	<u>140-190</u>
Gauge	6	4	1/4"	5/16"	3/8"
Amperes	170-240	230-320	260-360	300-450	350-600

WELDING EQUIPMENT

BESIDES THE welding machine and suitable electrodes, the accessories necessary for a welder are:

1. A substantial work table with a fairly heavy mild steel plate for a top.
2. *Leads.* Two are required — one from the machine to the electrode holder, called the electrode lead, and one from the job or work table back to the machine to complete the circuit, called the work or earth lead. These leads should be heavy enough to carry the required current without overheating. They must be kept in good condition and in close electrical contact with the holder and the work for the best utilisation of current.
3. *Electrode Holders.* These should be heavy enough not to overheat, and have well-insulated handles to avoid electric shocks and accidental arcing. Holders are available that are designed for continuous welding at high amperages. These are fully insulated and the jaws are made of metals having high heat conductivity.
4. *Shields.* These are necessary for protecting the eyes and face from glare and ultra-violet radiation from the arc, and spatter from the weld pool. Special tinted glass is used in the shields to absorb ultra-violet rays. A clear piece of replaceable glass is used in front of the coloured glass to protect it from spatter and smoke.
5. *Clothing.* Leather gauntlets and apron should be worn, and clothes should be of material that will deflect spatter and sparks.
6. *Chipping Hammer.* Used for deslagging of welds.
7. *Wire Brush.* Used for removing rust, cleaning slag off welds, etc.

WELDING POSITIONS AND WELD JOINTS

MOST MILD steel electrodes can be used in a number of positions. The sketches following show the positions in which welding may be done. Numerous applications call for welds to be made in positions intermediate between these. Some of the commoner types of weld joints are also shown.

FLAT POSITION (DOWNHAND WELDING)

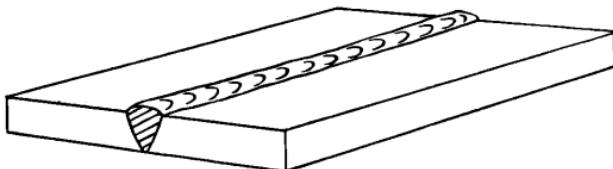


FIG. 18

Down Hand Butt Weld

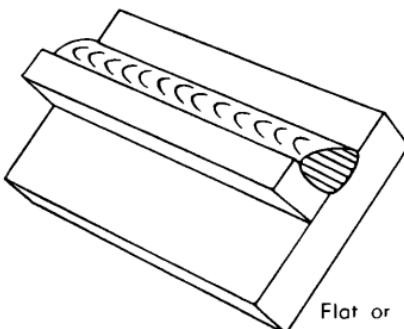


FIG. 19

Flat or Natural Fillet Weld

HORIZONTAL POSITION

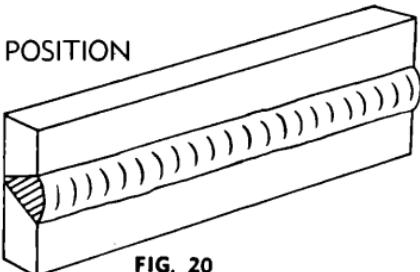


FIG. 20

HORIZONTAL – VERTICAL
(HV) FILLET

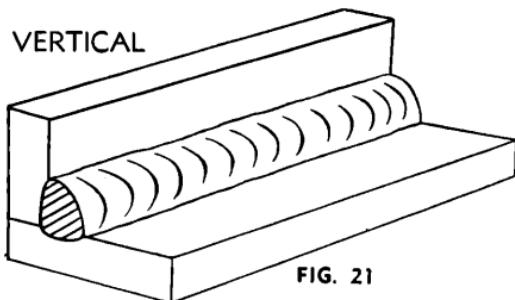


FIG. 21

VERTICAL POSITION

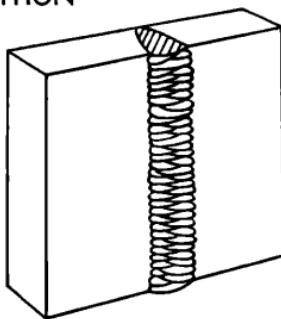


FIG. 22

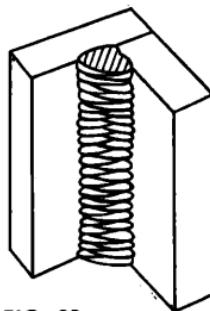


FIG. 23

OVERHEAD POSITION

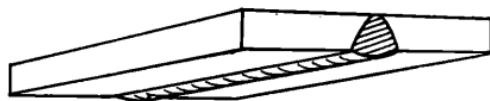


FIG. 24

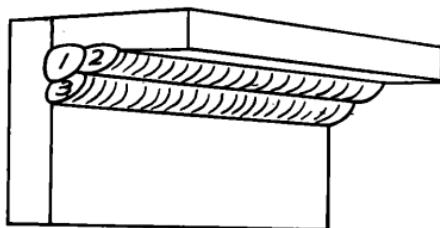


FIG. 25

CLOSE BUTT JOINT



FIG. 26

SINGLE VEE BUTT JOINT

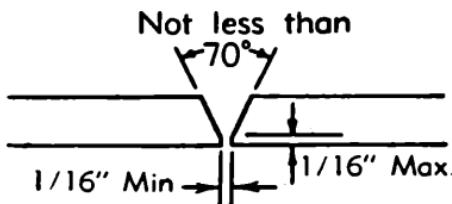


FIG. 27

DOUBLE VEE BUTT JOINT

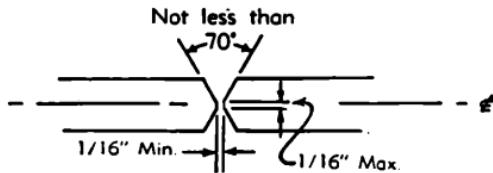


FIG. 28

OPEN SQUARE BUTT JOINT

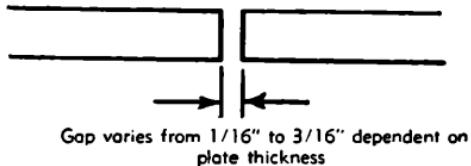


FIG. 29

SINGLE U BUTT JOINT

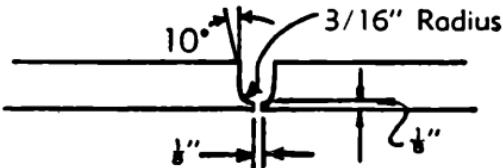


FIG. 30

DOUBLE U BUTT JOINT

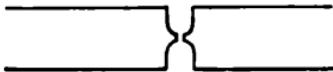


FIG. 31

SINGLE VEE BUTT JOINT

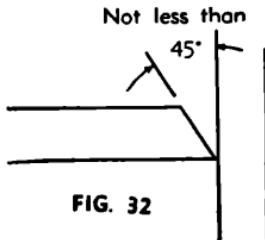


FIG. 32

SINGLE J BUTT JOINT

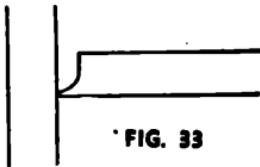


FIG. 33

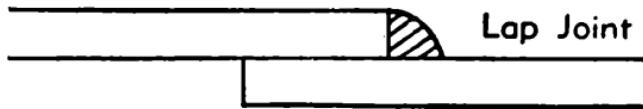


FIG. 34

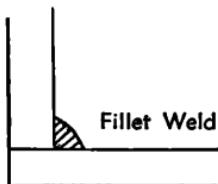


FIG. 35

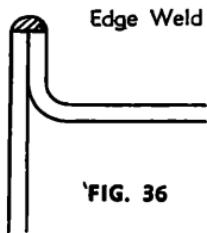


FIG. 36

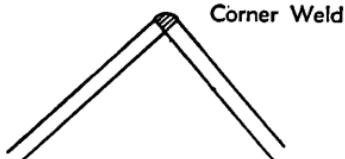


FIG. 37

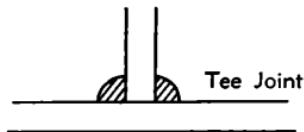


FIG. 38

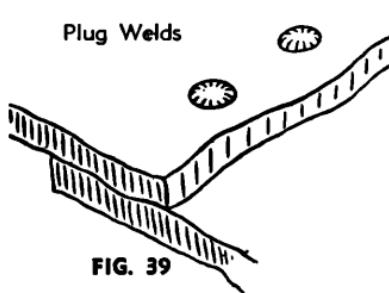


FIG. 39

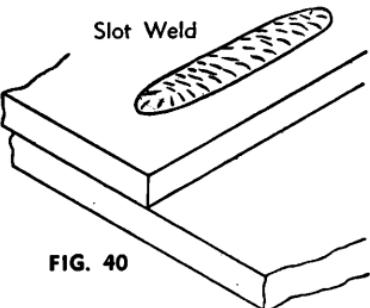


FIG. 40

WELDING TECHNIQUE

A Word to Beginners

FOR THOSE who have not yet done any welding, the simplest way to learn is to run beads on a piece of scrap plate. Use mild steel plate about half-inch thick and an 8-gauge electrode. Clean any paint, loose scale or grease off the plate and set it firmly on the work bench so that welding can be carried out in the downhand position. Make sure that the earth clamp is making good electrical contact with the work, either directly or through the work table. For light gauge material, always clamp the earth lead directly to the job, otherwise a poor circuit will probably result.

ELECTRODE — TYPE AND SIZE:

The type of electrode will depend on the material to be welded and the position in which welding is to be carried out (i.e., whether downhand, vertical or overhead). In our case, the general purpose VODEX electrode is the most suitable. We have already chosen an 8-gauge electrode, but for other jobs the gauge used will depend on the thickness of the material and the type of joint to be welded. For example, on thin material a small gauge is required, otherwise holes will burn through. The electrode size should allow for adequate root penetration. On Vee butt joints, the root run is often made with 8- or 10-gauge electrodes and the remaining welding is done with 6-gauge electrodes.

Generally, the maximum size which may be used on vertical and overhead welding is 6-gauge, but these more specialised applications can be left for the moment while we concentrate on downhand welding.

AMPERAGE:

Suitable amperages for the various gauges of electrodes are usually printed on the packets. These amperages may be varied to suit conditions—welds on thin plate require low amperages to prevent burn-through, while high welding rates or deep penetration of the weld

metal require higher amperages. For 8-gauge, set the machine at about 160 amps.

There are several effects produced by incorrect amperage. If it is too high, you will notice that the spatter becomes excessive, and the weld pool becomes very hot, producing a flattened bead with elongated ripple marks, and the electrode overheats. If the current is too low, it is difficult to maintain the arc and prevent the electrode from sticking, the bead is high and rounded, with poor edge fusion, and penetration is slight. Figures 41, 42 and 43 show the effects of different amperages.

WELDING CURRENT

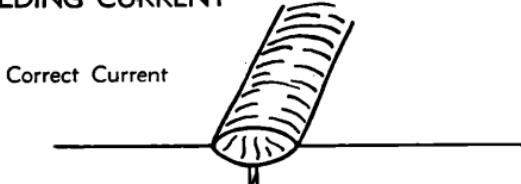


FIG. 41

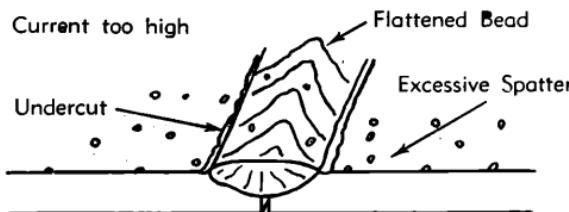


FIG. 42

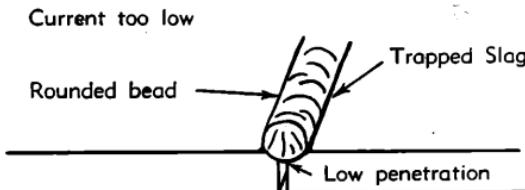


FIG. 43

THE WELDER:

Place yourself in a comfortable position before beginning to weld. Get a seat of suitable height and do as much work as possible sitting down. Don't hold your body tense. A taut attitude of mind and a tense body will soon make you tired. Relax and you will find that the job becomes much easier. You can add much to your peace of mind by wearing a leather apron and gauntlets. You won't be worrying then about sparks setting alight to your clothes.

Place the work so that the direction of welding is across, rather than to or from, your body. The electrode holder lead should be clear of any obstruction so that you can move your arm freely along as the electrode burns down. If the lead is slung around the back of your neck and over your shoulder, it allows greater freedom of movement and takes a lot of weight off your hand. Be sure the insulation on your cable is not faulty, otherwise you are risking an electric shock.

STRIKING THE ARC:

Practise this on a piece of scrap plate before going on to more exacting work. You may at first experience difficulty due to the tip of the electrode "sticking" to the work piece. It is caused by making too heavy a contact with the work and failing to withdraw the electrode quickly enough. A low amperage will accentuate it. This freezing-on of the tip may be overcome by scratching the electrode along the plate surface in the same way as a match is struck. As soon as the arc is established, withdraw the electrode very slightly (1/16-in.) from the plate, and feed it into the weld pool as it melts down. (See Fig. 44.)

Another difficulty you may meet is the tendency, after the arc is struck, to withdraw the electrode so far that the arc is broken again. A little practice will soon remedy both of these faults.

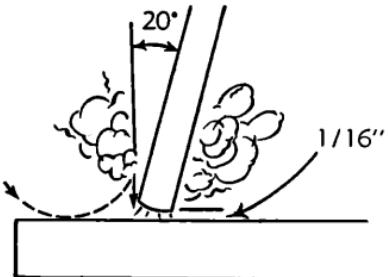


FIG. 44

ARC LENGTH:

The securing of an arc length necessary to produce a neat weld soon becomes almost automatic. You will find that a long arc produces more heat. A very long arc produces a crackling or spluttering noise and the weld metal comes across in large, irregular blobs. The weld bead is flattened and spatter increases. A short arc is essential if a high quality weld is to be obtained, although if it is too short there is the danger of it being blanketed by the slag and the electrode tip being frozen in. If this should happen, give the electrode a quick twist back over the weld to detach it.

RATE OF TRAVEL:

After the arc is struck, your next concern is to maintain it, and this requires moving the electrode tip towards the molten pool at the same rate it is melting away. At the same time, the electrode has to move along the plate to form a bead. The electrode is directed at the weld pool at about 20 deg. from the vertical. The rate of travel has to be adjusted so that a well-formed bead is produced. If the travel is too fast, the bead will be narrow and strung out and may even be broken up into individual globules. If the travel is too slow, the weld metal piles up and the bead is too large.

MAKING WELDED JOINTS:

Having attained some skill in the handling of an electrode, you will be ready to go on to make up welded joints.

BUTT WELDS:

Set up two plates with their edges parallel, as shown in Figure 45, allowing about 1/8-in. gap between them, and tack weld at both ends (MAPEX is ideal for tack-welding). This is to prevent contraction stresses from the cooling weld metal pulling the plates out of alignment. Plates thicker than 1/4-in. should have their mating edges bevelled to form a 70-90 deg. included angle. This allows full penetration of the weld metal to the root. Using an 8-gauge FASTEX 5 or VODEX electrode at 160 amps., deposit a run of weld metal in the bottom of the joint. Do not weave the electrode, but maintain a steady rate of travel along the joint sufficient to produce a well-formed bead. At first you may notice a tendency for undercut to form, but keeping the arc length short, the angle of the electrode at about 20 deg. from vertical, and the rate of travel not too fast, will help to eliminate this. The electrode needs to be moved along fast enough to prevent the slag pool from getting ahead of the arc. To complete the joint in thin plate, turn the job over, clean the slag out of the back and deposit a similar weld.

Heavy plate will require several runs to complete the joint. After completing the first run, chip the slag out and clean the weld with a wire brush. It is important to do this to prevent slag being trapped by the second run. Subsequent runs are then deposited using either a weave technique or single beads laid down in the sequence shown in Figure 10. The width of weave should not be more than three times the core wire diameter. When the joint is completely filled, the back is either machined, ground or gouged out to remove slag which may be trapped in the root, and to prepare a suitable joint for depositing the backing run. If a backing bar is used, it is not usually necessary to remove this, since it serves

BUTT WELD

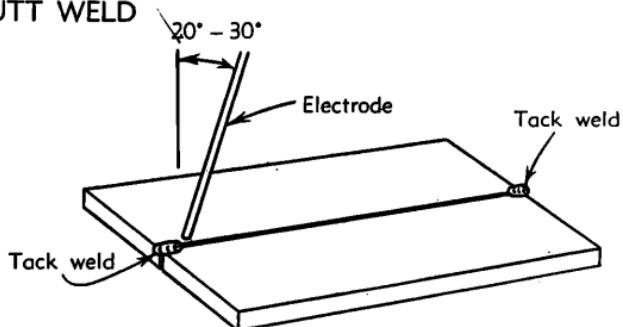


FIG. 45

H. V. FILLET WELD

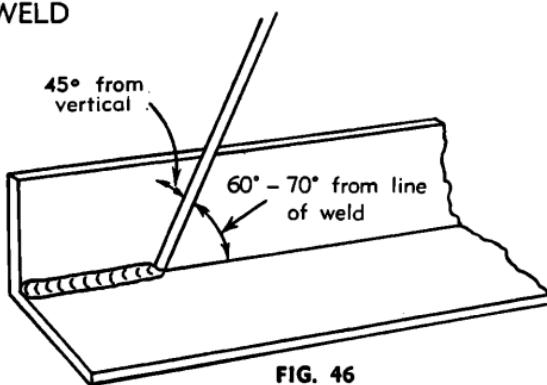


FIG. 46

BUILD-UP SEQUENCE FOR H. V. FILLET

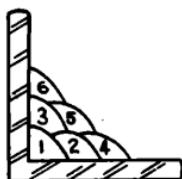


FIG. 47

a similar purpose to the backing run in securing proper fusion at the root of the weld.

FILLET WELDS:

These are welds of approximately triangular cross-section made by depositing metal in the corner of two faces meeting at right angles (Fig. 35).

A piece of angle iron is a suitable specimen with which to begin, or two lengths of strip steel may be tacked together at right angles. Position the angle iron so that the two legs are at 45 deg. to the bench and run in a weld bead using a similar technique as for butt welds, using an 8-gauge VODEX electrode at 160 amps. When you are familiar with this, position another piece of angle iron with one leg horizontal and the other vertical. This is known as a horizontal-vertical (HV) fillet. Strike the arc and immediately bring the electrode to a position perpendicular to the line of the fillet and about 45 deg. from the vertical. Some electrodes require to be sloped about 20 deg. away from the perpendicular position to prevent slag from running ahead of the weld (see Fig. 46). Do not attempt to build up much larger than 1-in. leg length with an 8-gauge electrode, otherwise the weld metal tends to sag towards the base, and undercut forms on the vertical leg. Multi-runs can be made as shown in Figure 47. Weaving in HV fillet welds is undesirable.

VERTICAL WELDS:

Tack weld a three feet length of angle iron to your work bench in an upright position. Use an 8-gauge VODEX electrode and set the current at 140 amps. Make yourself comfortable on a seat in front of the job and strike the arc in the corner of the fillet. The electrode needs to be about 10 deg. from the horizontal to enable a good bead to be deposited (see Fig. 48). Use a short arc, and do not attempt to weave on the first run. When the first run has been completed, deslag the weld deposit and begin the second run at the bottom.

This time a slight weaving motion is necessary to cover the first run and obtain good fusion at the edges. At the completion of each side motion, pause for a moment to allow weld metal to build up at the edges, otherwise undercut will form and too much metal will accumulate in the centre of the weld. Figure 49 illustrates multi-run technique and Figures 50 and 51 show the effects of pausing at the edge of weave and of too rapidly weaving.

OVERHEAD WELDS:

Apart from the rather awkward position necessary overhead welding is not much more difficult than downhand welding. Set up a specimen for overhead welding by first tack welding a length of angle iron at right angles to another piece of angle or a length of waste pipe. Then tack this to the work bench or hold in a vice so that the specimen is positioned in the overhead position as shown in the sketch. The electrode is held at 45 deg. to the horizontal and tilted 10 deg. in the line of travel (Fig. 52 shows this). The tip of the electrode may be touched lightly on the metal, which helps to give a steady run.

A weave technique is not advisable for overhead fillet welds. Use an 8-gauge **VODEX** electrode at 160 amps., and deposit the first run by simply drawing the electrode along at a steady rate. You will notice that the weld deposit is rather convex, due to the effect of gravity before the metal freezes. Second and third runs are deposited in the order shown in Figure 53.

VERTICAL FILLET WELDS

SINGLE RUN

Electrode at
right angles, or 10° from
perpendicular

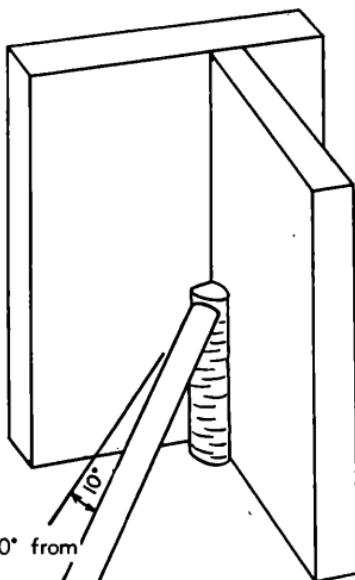


FIG. 48

MULTI RUN

Weaving motion
for second and
subsequent runs

Pause at edge
of weave

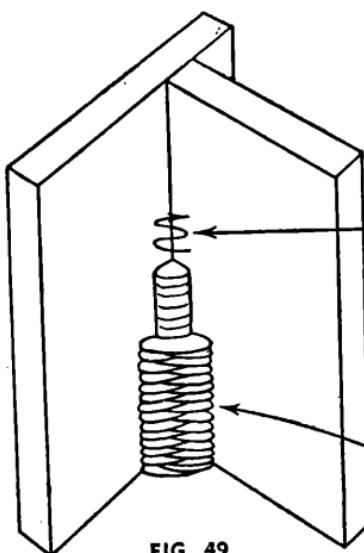


FIG. 49

VERTICAL FILLET WELDS

CORRECT

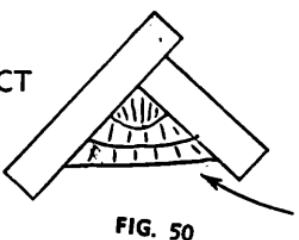


FIG. 50

Pause at edge of weave allows weld metal to build up, and eliminates undercut

INCORRECT

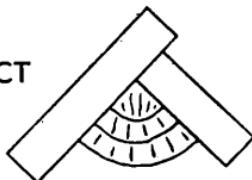


FIG. 51

Note weld contour when insufficient pause at edge of weave

OVERHEAD FILLET WELD

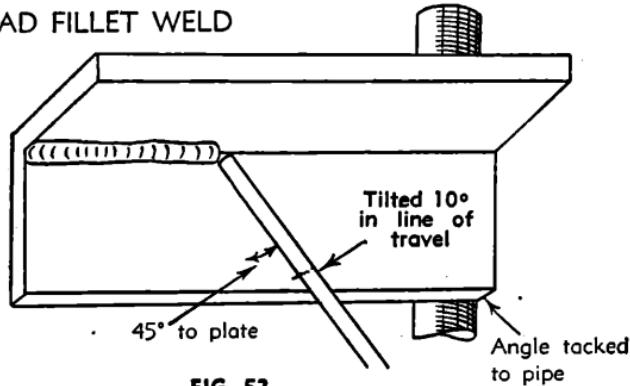


FIG. 52

BUILD UP SEQUENCE

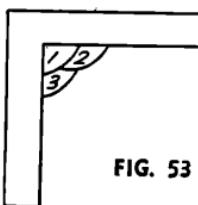


FIG. 53

DEFECTS DUE TO FAULTY TECHNIQUE

1. UNDERCUT:

THIS REDUCTION in cross section weakens the joint and creates a slag trap.

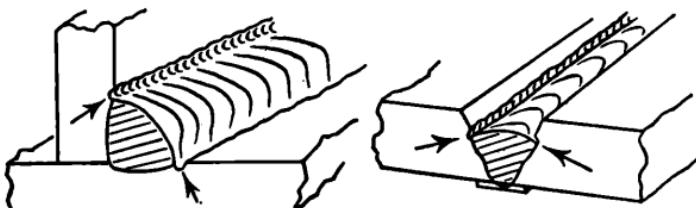


FIG. 54

FIG. 55

<i>Cause</i>	<i>Remedy</i>
High amperage	Reduce amperage.
Arc too long	Keep shorter arc.
Angle of electrode too inclined to joint face	Electrode should not be inclined less than 45 deg. to vertical face.
Joint preparation does not allow correct electrode angle	Allow more room in joint for manipulation of electrode.
Electrode too large for joint	Use smaller gauge electrode
Insufficient depositing time at edge of weave	Pause for a moment at edge of weave to allow build-up. (Weaving is more likely to produce undercut than a straight run. Therefore, where possible, use straight runs.)

2. SLAG INCLUSIONS:

Non-metallic particles trapped in the weld metal are called slag inclusions. They may seriously reduce the strength of the welded joint.

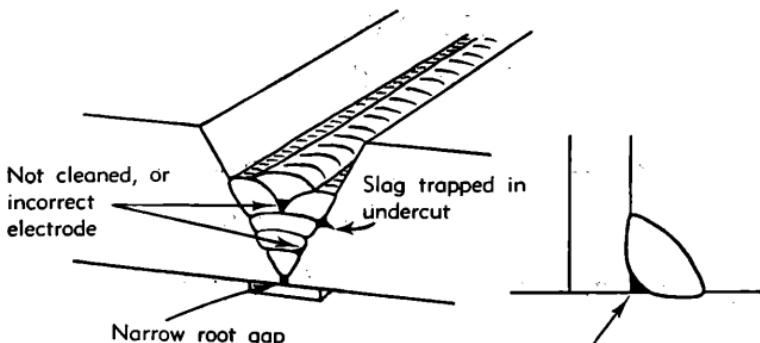


FIG. 56

FIG. 57

Cause

May be trapped in undercut from previous run

Joint preparation too restricted

Irregular deposits allow slag to be trapped

Lack of penetration with slag being trapped beneath weld bead

Rust or mill scale, preventing full fusion

Wrong electrode for position in which welding is done

If slag is present in a weld, chip, grind or flame gouge until removed, and re-weld.

Remedy

If bad undercut present, clean slag out and cover with run from small gauge electrode.

Allow for adequate penetration and room for cleaning out slag.

If very bad, chip or grind out irregularities.

Use smaller electrode with sufficient amperage to give adequate penetration. Use suitable tools to remove all slag from corners, etc.

Clean joint before welding.

Use electrodes designed for position in which welding is done, else proper control of slag is difficult.

9 ✓
with torch

INCOMPLETE PENETRATION:

A gap left by failure of the weld metal to fill the root.

<i>Cause</i>	<i>Remedy</i>
Amps. too low	Increase current.
Electrode too large for joint	Use smaller electrode.
Insufficient gap	Allow wider gap.
Angle of electrode	If too inclined, does not give penetration. Keep nearer to right angle to weld axis.
Incorrect sequence	Use correct build-up sequence (see Fig. 10).

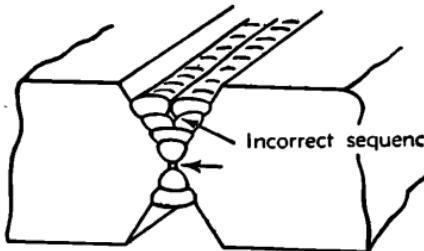


FIG. 58

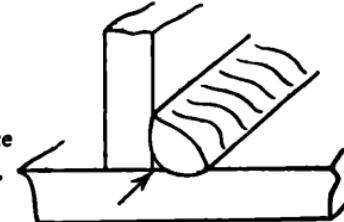


FIG. 59

3. LACK OF FUSION:

Portions of the weld run do not fuse to the surface of the metal or edge of the joint.

<i>Cause</i>	<i>Remedy</i>
Small electrodes used on heavy cold plate	Use larger electrodes (preheat may be desirable).
Amperage too low	Increase current.
Wrong electrode angle	Adjust angle so the arc is directed more into parent metal.
Speed of travel	If too high, does not allow time for proper fusion.
Scale or dirt on joint surface	Clean surface before welding.

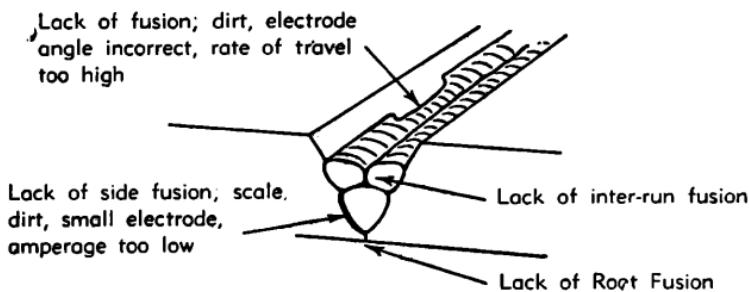


FIG. 60

NOTE: In overcoming these faults, it is often an advantage if the job can be positioned to allow welding to be done in the downhand position.

DISTORTION

DISTORTION IN some degree is present in all forms of welding. In many cases it is so small that it is barely perceptible, but in other cases allowance has to be made before welding commences for the distortion that will subsequently occur. The study of distortion is so complex that only a brief outline can be attempted here.

THE CAUSE OF DISTORTION:

Distortion is caused by:

1. Contraction of the weld metal from the molten state to atmospheric temperature.
2. Different rates of expansion and contraction between the metal adjacent to and at a distance from the weld.

1. Contraction of Weld Metal:

Molten steel shrinks approximately 11 per cent. in volume on cooling to room temperature. This means that a cube of molten metal would contract approximately 2.2 per cent. in each of its three dimensions. In a welded joint, the molten metal becomes attached to the side of the joint and cannot contract freely. Therefore, cooling causes the weld metal to flow plastically, that is, the weld metal itself has to stretch if it is to overcome the effect of the shrinking volume and still be attached to the edge of the joint. If the restraint is very great, as, for example, in a heavy section of plate, the weld metal may crack. Even in cases where the weld metal does not crack, there will still remain stresses "locked-up" in the structure. If the joint material is relatively weak, for example, a butt joint in 14-gauge sheet, the contracting weld metal may cause the sheet to become distorted.

2. *Expansion and Contraction of Parent Metal in the Fusion Zone:*

While welding is proceeding, a relatively small volume of the adjacent plate material is heated to a very high temperature and attempts to expand in all directions. It is able to do this freely at right angles to the surface of the plate (i.e. "through the weld"), but when it attempts to expand "across the weld" or "along the weld", it meets considerable resistance, and to fulfil the desire for continued expansion, it has to deform plastically, that is, the metal adjacent to the weld is at a high temperature and hence rather soft, and, by expanding, pushes against the cooler, harder metal farther away, and tends to bulge (or is "upset"). When the weld area begins to cool, the "upset" metal attempts to contract as much as it expanded, but, because it has been "upset", it does not resume its former shape, and the contraction of the new shape exerts a strong pull on adjacent metal. Several things can then happen. The metal in the weld area is stretched (plastic deformation), the job may be pulled out of shape by the powerful contraction stresses (distortion), or the weld may crack. In any case, there will remain "locked-up" stresses in the job. Figures 61 and 62 illustrate how distortion is created.

OVERCOMING DISTORTION EFFECTS:

There are several methods of minimising distortion effects.

1. *Peening:*

This is done by hammering the weld while it is still hot. The weld metal is flattened slightly and because of this the tensile stresses are reduced a little. The effect of peening is relatively shallow, and is not advisable on the last layer.

2. *Distribution of Stresses:*

Distortion may be reduced by selecting a welding sequence which will distribute the stresses suitably so that they tend to cancel each other out. See Figures 11 to 16 for various weld sequences. Choice of a suitable weld sequence is probably the most effective method of overcoming distortion, although an unsuitable sequence may exaggerate it. Simultaneous welding of both sides of a joint by two welders is often successful in eliminating distortion.

3. *Restraint of Parts:*

Forcible restraint of the components being welded is often used to prevent distortion. Jigs, positioners and tack welds are methods employed with this in view.

4. *Preheating:*

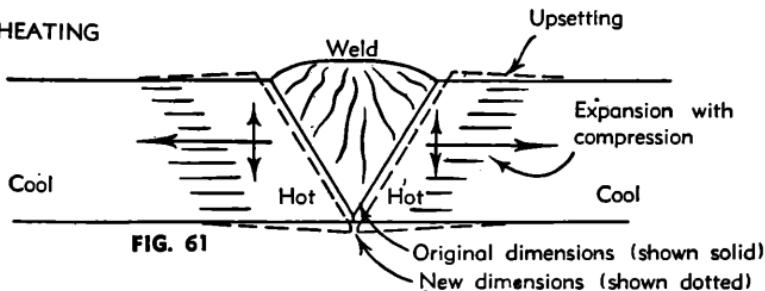
Suitable preheating of parts of the structure other than the area to be welded can be sometimes used to reduce distortion. Figure 65 shows a simple application. By removing the heating source from *a* and *c* as soon as welding is completed, the sections *a*, *b* and *c* will contract at a similar rate, thus reducing distortion.

5. *Presetting:*

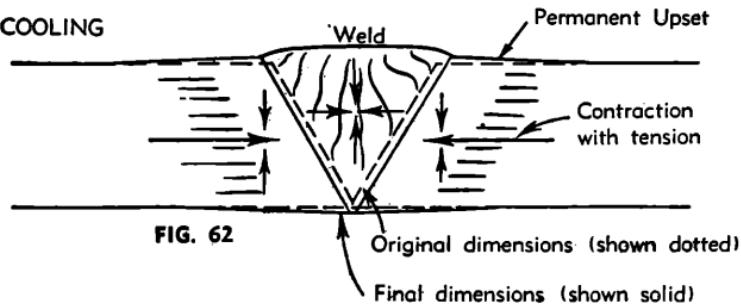
It is possible in some cases to tell from past experience or to find by trial and error (or less frequently, to calculate) how much distortion will take place in a given welded structure. By correct pre-setting of the components to be welded, contractual stresses can be made to pull the parts into correct alignment. A simple example is shown in Figures 63 and 64.

THE CAUSE OF DISTORTION

HEATING



COOLING



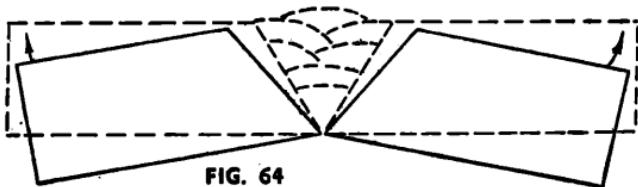
SKETCHES EXAGGERATED FOR CLARITY

TRANSVERSE ANGULAR DISTORTION

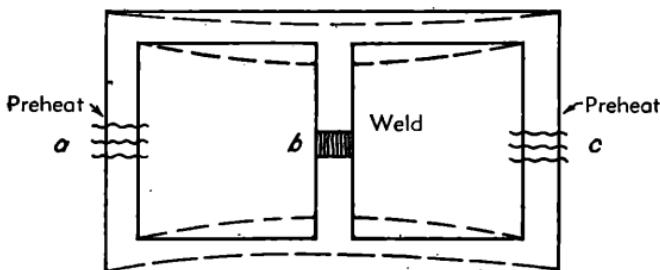


FIG. 63

PRINCIPLE OF PRESETTING



REDUCTION OF DISTORTION BY PREHEATING



Dotted lines show effect if
no preheat is used

FIG. 65

EXAMPLES OF DISTORTION

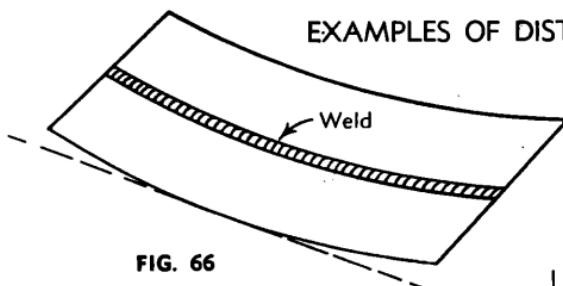


FIG. 66



FIG. 67



FIG. 68

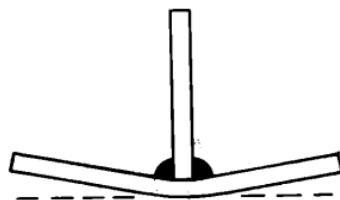


FIG. 69



FIG. 70



FIG. 71

METALLURGICAL FACTS ABOUT IRON AND STEEL

Probably 90 per cent. or more of all arc welding is done on some alloy of iron. Commercially pure iron is a silver grey, very ductile metal of low tensile strength—too weak for most engineering applications. To give it the necessary hardness and strength other elements, principally carbon, must be added. When the carbon content ranges from .10 to 1.5 per cent. the material is known as steel—from 2.50 to 4.0 per cent., it is cast iron.

In addition to carbon, other alloys are also used to promote strength, ductility and resistance to corrosion, abrasion, and impact; such elements as nickel, chromium, molybdenum, and copper in general increase hardness and enhance the physical properties. They are used extensively in the popular constructional steels. Other elements, such as tungsten and cobalt, are important in the production of high-speed tool steels, not only to increase hardness, but to retain the cutting edge at relatively high temperatures.

Elements such as aluminium, titanium, zirconium, vanadium and boron are especially useful in the removal of certain impurities in steel, thus improving its grain structure and response to hardening when heat-treated.

As phosphorus and sulphur are generally considered detrimental except in steels where free cutting is a prime requisite, these elements are usually not permitted to exceed .05 per cent. In excess of this amount, sulphur causes porosity and brittleness in welding. Therefore, it is necessary to exercise care when welding free cutting steels, which have a sulphur content of from .09 to .20 per cent. Cold finished steels of this type are the cause of much unsatisfactory welding and as, unfortunately, no simple means, such as the spark test, will disclose the amount of sulphur, the only safe course is a careful specification or a laboratory analysis.

In making alloy steels, the physical properties depend not only on the elements added, but upon the heat treatment as well. The degree and duration of heat and the rate of cooling have a profound effect upon the hardness and grain structure. Steels which possess marked hardening ability, such as those with over .30 per cent. carbon, and varying amounts of other elements, harden in proportion to their rate of cooling. Therefore, in welding, the rapid cooling induced by the cold surrounding area causes such steels to become so hard that they are difficult or impossible to machine. Rapid cooling also sets up stresses which unless relieved by later heat treatment produce cracks and almost certain failure. To prevent such conditions, the work or parent metal should be pre-heated and welded while hot, the exact temperature depending upon the type of material and its response to hardening. This permits the weld and adjoining metal to cool more slowly and more evenly, reducing hardness and producing a more uniform grain structure throughout. More is said of this subject under "High Tensile Steels."

It should be remembered that the above conditions apply only to steels having more than .30 per cent. carbon and particularly when other alloys are present. By far the most welded fabrications today are of structural steel—angles, beams, channels, plates, etc.—all of which have low carbon and low hardening ability. When alloys are present in such stock the amount is so small as to be negligible as a hardening factor, therefore the precaution of preheating is unnecessary.

MILD STEEL

THIS IS essentially iron with up to .30 per cent. carbon alloyed with it, and containing usually between .4 and 1 per cent. manganese, a little silicon, and small amounts of sulphur and phosphorus as impurities.

WELDING TROUBLES

HOT CRACKING:

<i>Cause</i>	<i>Remedy</i>
Sulphur, introduced from the steel or surface impurities, causes the weld metal to crack, especially when under restraint.	Use Fortex 35 electrode on high sulphur steels. Clean surface if dirty.
Rigidity of joint, which causes the weld metal to hot-tear before completely solidified.	Re-design to relieve weld joint of severe stresses, or use crack-resistant Fortex 35.
Insufficient throat thickness.	Travel slightly slower to allow greater build-up in throat.
Current. Too high a welding current will produce a concave weld, and, by overheating the metal, induce large crystals to form, which are likely to hot-tear.	Use lower current.
Wide gap to be bridged, making throat thickness narrow.	Closer set-up tolerance, or deposit run of weld each side of gap to close distance.

POROSITY:

<i>Cause</i>	<i>Remedy</i>
High sulphur in the steel will cause porosity due to gas being evolved.	Use Fortex 35 electrode on high sulphur steels.
Damp electrodes will cause porosity at the beginning of a run.	Dry electrodes before use.
Overdried electrodes. Most electrodes, except the low hydrogen types, require some moisture for best running characteristics. Overdrying will cause porosity towards end of run.	For further details concerning drying of electrodes, see section "The Welding Electrode."
Excessive current, which overheats the electrode, sometimes causes porosity.	Use lower amperage.
Surface impurities, such as oil, grease, paint, etc., will sometimes cause porosity.	Clean joint before welding.

ELECTRODES RECOMMENDED BY MUREX FOR THE WELDING OF MILD STEEL

VODEX: These electrodes are designed for welding mild and medium tensile steels in all positions. They are especially suitable for vertical and overhead work and, for this reason, are very popular for hydro-electric schemes, ship-building, oil refineries, bridge-building and similar heavy construction jobs. The electrode possesses excellent running characteristics and the slag is easily removed. The weld metal has high mechanical properties. The radiographic standard is of good commercial quality.

FASTEX 5: Is designed for welding mild and medium tensile steels, primarily in the downhand position, but may be used successfully for positional welding. It is very easy to use. There is little spatter or undercut and the slag is self-releasing. Amperages much higher than normal may be used, giving high production rates. Light or heavy fillets may be deposited with any one gauge, and light gauge steel may be welded with this electrode. The deposit may be hot-forged.

MAPEX: This is a general purpose electrode suitable for welding in all positions. It is easy to use, and a desirable feature is its ability to deposit fillet welds by welding in the vertical down position. It has a very stable arc and its ease of restriking makes it ideal for tack-welding operations.

CONTEX: These electrodes are designed to simplify the welding of mild steel in the downhand and overhead positions, using the "touch-weld" technique. The electrode tip is touched against the work and this light contact is maintained throughout the run. A neat uniform deposit is obtained, and the slag is self-releasing. Very long runs may be made on thin gauge material with relatively large electrodes.

IRONEX A: The heavy flux coating of IRONEX A electrodes contains a high percentage of Iron powder which permits the use of high welding currents and also contributes to the weld metal produced so that an accelerated rate of deposition is obtained. The electrode is easy to handle using either the touch-weld technique or a short arc. The weld deposit appearance is very pleasing and slag removal is excellent. IRONEX A may be used in flat, oblique and horizontal positions.

DEEPEX: Is designed to produce full penetration welds on square butt joints up to $\frac{1}{2}$ -in. thick. The cost of edge preparation of plates may thus be greatly reduced.

MOLEX: A molybdenum-bearing mild steel electrode specially suitable for welding in all positions and where molybdenum of 0.4-0.6 per cent. is necessary for creep resistance at elevated temperatures.

P.V.: Specially designed for deep groove type preparations in thick, mild steel plate in the downhand position. Ideally suited for work on pressure vessels subjected to Lloyds Class I requirements and where requiring weld metal which has a high standard of radiographic cleanliness for excellent mechanical properties.

T.P.W.: A special 16-gauge electrode for light plate welding suitable for inside fillets.

HIGH TENSILE AND ALLOY STEELS

THESE ARE produced to increase strength without increasing weight, and this is attained by adding alloys, such as manganese, chromium, nickel and molybdenum, or by increasing the carbon content beyond that of mild steel.

The result of this is usually to make the steel more difficult to weld satisfactorily.

EFFECTS OF WELDING:

The two most prominent effects of welding these steels are the formation of a hardened zone in the weld area, and, if suitable precautions are not taken, the occurrence in this zone of underbead cracks.

1. *The Hardened Zone:*

Let us picture what happens when welding is carried out on a sample of hardenable steel.

At the point where the arc is playing, the parent metal is heated to its melting point. Immediately below the molten pool, the metal is white hot, with decreasing temperatures further away. When the arc moves on, the cooler metal below the weld bead has a quenching effect on the very hot metal, with the formation of a hard zone.

The hardness of this zone depends on a number of factors, among them being:

- (a) Composition of the basis metal.
- (b) Temperature of basis metal.
- (c) Mass of basis metal adjacent to the weld.
- (d) Heat input (amperage, amount of build-up per electrode).

(b), (c) and (d) will affect rate of cooling and consequent hardness.

The effect of this hardened zone is to reduce the ductility of the parent metal in the weld area, and this, in some applications, may lead to failure of the joint.

2. *Underbead Cracking:*

The tendency for underbead cracking to occur is due largely to the presence of hydrogen in the weld metal.

When steel is heated to approximately 720 deg. C., the crystal structure changes to a form known as austenite, and in this state it is able to "absorb" appreciable quantities of hydrogen, such as may be introduced from the arc atmosphere.

When the steel cools again after welding, the crystal structure transforms from austenite to another form, generally martensite. In this state, the steel cannot retain the hydrogen, which diffuses into microscopic cavities in the heat-affected area, where it remains and builds up tremendous pressure. If sufficient hydrogen is present and the heat-affected zone hard enough, this pressure will cause underbead cracking.

If the hardness of the heat-affected zone exceeds 350 V.P.N. (Vickers Pyramid Number), there is a danger that underbead cracks will form when ordinary mild steel electrodes are used.

It is not necessary for the weld to be under restraint for these cracks to form. Even unrestrained welds, if sufficient hardness develops, will crack.

Hard zone cracks are generally not visible on the surface, which makes it essential to use a proper technique to ensure their absence.

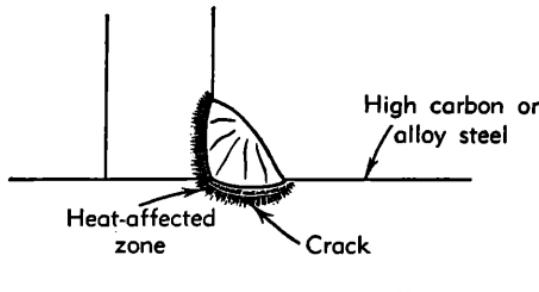


FIG. 72

HOW TO WELD HARDENABLE STEELS:

Reduce hard zone by:

1. Preheating. This slows down the rate of cooling after welding, and reduces the quenching effect on hot metal. The preheat necessary increases with increasing carbon and alloys, and a heavy mass of metal requires a higher preheat than a thin section.
2. Using higher amperage, which produces more heat and slows down rate of cooling.
3. Larger electrode sizes, since they require higher amperages, will also introduce more heat into weld.
4. Larger deposits. Short, heavy runs deposited from each electrode raise the area of welding to a higher temperature, and slow down cooling.
5. Post-weld treatment, consisting of tempering or softening in a furnace, with torches, or by induction heating, is sometimes used to reduce the hardness of the heat-affected zone.

Avoid underbead cracking by:

1. Using correct electrodes. The low-hydrogen type, Fortrex 35, or austenitic type Armex 3 should be used. The Fortrex 35 coating has a very low hydrogen content, and is used for welding high tensile steels, with freedom from underbead cracking. The weld metal has high ductility, and excellent impact strength even at very low temperatures.

Armex 3 deposits austenitic weld metal which retains hydrogen and prevents it from diffusing into the hard zone. It has been designed for welding very hardenable steels with a minimum of preheating. It is very resistant to hot-cracking—a common fault with some austenitic type electrodes.

2. Using preheat, higher amperage, heavy runs, etc. The same precautions used for reducing the hardness of the heat-affected zone also assist in preventing underbead cracks, firstly, because a zone of lower hardness is less likely to crack, and secondly, because slower

cooling allows more hydrogen to escape from the weld to the atmosphere.

ELECTRODES RECOMMENDED BY MUREX FOR THE WELDING OF HIGH TENSILE AND ALLOY STEELS

FORTREX 35:

A low hydrogen electrode for welding carbon and low alloy high tensile steels with freedom from hard zone cracking. It is outstanding in its class for ease of use in positional welding. Weld metal tensile and impact strengths and ductility are high, and radiographic clarity is excellent. It is suitable for use on free-machining steels, as a buffer layer on hardfacing applications, and for maintenance work on "unknown" steels.

ARMEX 2 and 3:

Downhand and all-positional austenitic stainless steel electrodes respectively, for welding high tensile steels normally considered unweldable. Originally designed for welding armour plate, they are particularly suitable for field applications where preheating facilities are limited. They have been found excellent for joining stainless steel to mild steel. Weld metal tensile strength is 40-45 tons/sq. in. with high ductility.

SUPREX A, B and C:

A series of low hydrogen electrodes has been developed to weld the special alloy creep-resisting steels now being used widely in oil refineries, steam generating plant and chemical industries. The chemical analysis and mechanical properties closely match those of the commonest types of these steels. Running characteristics are very good; radiographic clarity is high.

Suprex A: For 1½% chromium—½% molybdenum steels.

Suprex B: For 2½% chromium—1% molybdenum steels.

Suprex C: For 4-6% chromium—½% molybdenum steels.

STAINLESS STEELS

THESE ARE more accurately called corrosion- and heat-resistant steels. They are iron alloys which owe their resistance to corrosion and high temperatures to the presence of chromium alone, or chromium and nickel. Small amounts of other alloys, e.g., titanium, tungsten, molybdenum, niobium (columbium), are sometimes added.

The effect of chromium is to form a tough, impermeable film of oxide on the steel, which resists further attack by corrodents. If this film becomes damaged, it immediately re-forms, and continues its protective action. The presence of nickel, in sufficient quantity, increases this corrosion resistance and also increases the strength of the steel at high temperatures.

TYPES:

There is a large range of alloys in the stainless steel series.

1. *Plain Chromium Steels:*

(a) *Martensitic Stainless Steels*—12-16 per cent. Cr.:

Used for cutlery, spindles and shafts, and applications where good resistance to corrosion and scaling at high temperatures is desired. Can be hardened by heat-treatment.

(b) *Ferritic Stainless Steels*—16-30 per cent. Cr.:

Used where very high temperature scaling resistance is needed. Also has very good corrosion resistance. Common applications are in furnace parts, oil burners, carburising pots, acid containers, etc.

They are not hardened by heat-treatment, and are subject to grain growth at elevated temperatures, which makes them brittle when cool, although they may still be tough at red heat.

2. *Austenitic Nickel-Chromium Steels.*

The most common of this series is the well-known 18/8 Cr-Ni stainless steel. Other compositions contain 25/20 Cr-Ni, 18/12 Cr-Ni, etc. The addition of 2-3% molybdenum increases resistance to corrosion by sulphuric acid.

The outstanding properties of these steels are their corrosion and heat-resistance. It is not possible to harden them by heat-treatment, but they work-harden rapidly. They are non-magnetic or only feebly magnetic.

They are used for a great variety of purposes, e.g., in chemical and food plants, gas turbines, furnaces and other high temperature applications.

Because of their good corrosion-resistance, and, in the case of austenitic steels, work-hardening ability, these types of steels are often used for hardfacing and building-up wearing parts by the arc welding process.

It is common practice to use low-cost steels for certain applications, and cover areas subject to corrosion and wear with the appropriate stainless steel weld metal. In this way considerable savings may be effected.

HOW TO WELD STAINLESS STEELS:

1. *Straight Chromium Steels:*

(a) *Martensitic Types* (12-16 per cent. Cr.):

These steels will harden when welded, and may be too brittle for the service desired. Therefore, a pre-heat of 400 deg. C., followed by slow cooling after welding, is desirable to keep down the hardness of the heat-affected zone. If possible, tempering at 650-700 deg. C. after welding should be carried out on the job to restore toughness.

Electrodes:

For most welding on these steels, e.g., building-up and joining small pieces, Chromex 1 is suitable. This deposits weld metal similar to the parent metal. For more ductile welds, Nicrex 1, Nicrex NDR or Armex 2 may be used.

When welding stainless steels, keep a short arc to avoid loss of chromium and other alloys.

(b) Ferritic Types (16-30 per cent, Cr.) :

These are not hardened very much by welding, but they suffer from excessive grain growth if raised to high temperatures, and this makes them brittle when they cool again. The amount of grain growth will depend on the time for which the steel is at the high temperature.

For the strongest weld joint, use a preheat of 150-200 deg. C. If multi-runs are necessary, the interpass temperature should not exceed 200 deg. C.

Post-weld treatment, consisting of tempering at 700-800 deg. C., helps to restore ductility to the heat-affected zone of the weld.

Electrodes:

For ferritic stainless steels in the range of 16-26 per cent. Cr., use Chromex 2. For 26-30 per cent. Cr. steels, use Chromex 3.

If a soft weld, capable of deformation is desired, Nicrex 1 or Armex 2 may be used. Both of these perform very satisfactorily on these steels, provided the presence of nickel can be tolerated under the service conditions required.

2. Austenitic Stainless Steels:

These are very similar to mild steel to weld. There are a few points of difference.

(a) Distortion:

Coefficient of expansion is 50 per cent. higher than mild steel, and the tendency to distort is consequently much greater.

Remedies:

Use frequent tack welds. Use balanced and distributed welds to prevent stress from building up, and to spread the heat evenly through the work.

Use jigs if possible, to hold the job firm during welding, and also to extract heat from the weld area.

Reduce heat input by employing the smallest bead size convenient, and a moderate amperage.

A small bead on each side of a plate gives less distortion than a heavy bead on one side.

(b) Cracking:

Certain types of austenitic welds are susceptible to cracking:

<i>Possible Cause</i>	<i>Remedy</i>
Restraint	Design to eliminate restraint at joint or build up larger bead.
Type of joint	Design to eliminate fillet welds, which are more prone to crack than butt welds.
Inadequate penetration	Pay attention to welding technique. Design joint to give easy access during welding.
Excessive currents	Use lower amperage.
Large root gap	Use small root gap and slower welding speed to give adequate build-up.
Bead shape	Concave beads more likely to crack. Hold electrode at smaller angle to give more convex build-up.
Fast welding speed	Use slower welding speed to give correct build-up over gap.
Weld metal composition	Electrodes which deposit wholly austenitic weld metal are particularly susceptible to hot-cracking. Weld metal containing a small amount of ferrite is not so likely to crack. For advice on this point, write to the Murex Research Department.

(c) *Weld Decay:*

If the plain Cr-Ni austenitic stainless steels are heated to 500-900 deg. C. and allowed to cool slowly, they become more easily corrodible. Such a condition exists in the heat-affected zone of a weld on this material, and a band is formed parallel to the weld where corrosion resistance is greatly lowered. This is believed to be due to the removal of chromium, as such, from the grain boundaries by carbon, and its precipitation as chromium carbide, leaving a chromium-dépleted alloy in the grain boundaries, which is of much lower corrosion resistance. When the steel is immersed in a corroding medium, these low-alloy areas are eaten out, and the grains of metal simply fall apart.

Titanium or niobium additions are frequently made to stainless steels and act as "stabilisers." These have a greater "hunger" for carbon than has chromium, and hence the grain boundaries are not depleted of chromium. Very low carbon stainless steels are also used to avoid weld decay.

If it is necessary to weld unstabilised material, and afterwards to restore corrosion resistance, it may be heated after welding to 1100 deg. C. and quenched. This technique is, of course, limited by the size of the job and its tendency to distort.

Unstabilised weld deposits will also exhibit weld decay, for example, where one weld crosses another. For this reason, most stainless steel electrodes are also stabilised. Niobium additions are always used in this case, titanium being unsuitable as this metal is oxidised in the electric arc, and goes into the slag.

ELECTRODES FOR 18/8 STAINLESS STEEL:

NICREX NDR and NICREX ND both deposit stabilised weld metal, and are suitable for welding plain and stabilised 18/8 types of stainless steel.

NICREX MC and NICREX AC are stabilised electrodes containing molybdenum, and are useful for applications requiring good resistance to sulphuric acid, sulphurous acid, some organic acids and chlorides.

Electrodes for 25/20 Cr-Ni Steels:

NICREX 1 is a suitable electrode for 25/20 steel. It can be used for scaling resistance at high temperature.

For advice on the welding of heat-resisting alloys of high alloy content, you are invited to call on the services of the Murex Research Department.

MUREX ELECTRODES FOR CORROSION-RESISTANT ALLOYS

RANGE OF ALLOYS COVERED	ELECTRODE
All plain chromium 12-14% stainless irons and steels	'Chromex 1'
All chromium alloys above 16% chromium, including hardening alloys	'Chromex 2'
Plain chromium alloys of 26-30% chromium	'Chromex 3'
All 18-8 chromium-nickel steels with or without titanium or niobium	'Nicrex NDR' 'Nicrex ND' 'Nicrex AC'
18-8 chromium-nickel steels with 2-3% molybdenum	'Nicrex MC' 'Nicrex AC'
18-8 chromium-nickel steels with 4% molybdenum	'Nicrex MC55'
Heat-resisting steels of the 23-11 class, with addition of tungsten	'Nicrex HR'
25-20 chromium-nickel steels for corrosion and heat-resisting purposes	'Nicrex 1'
18-18-3-2 chromium-nickel-molybdenum-copper steels	'Nicrex 2'
A range of heat-resisting alloys for furnace parts, 60% nickel, 20% chromium, 20% iron	'Nicrex 3'
80-15 nickel-chromium for heat-resisting purposes	'Nicrex 4'

MUREX CHROMIUM-NICKEL ELECTRODES FOR WELDING DISSIMILAR METALS

Plate	25/20 25/20/Ti	18/8/Ti 18/8/Cb	18/8/Mo	23/11/W	16-22 Cr	12-14 Cr
25/20 25/20/Ti	'Nicrex 1' or 'Nicrex 1 CB'					
18/8/Ti 18/8/Ti 18/8/Cb	'Nicrex ND' or 'Nicrex NDR'	'Nicrex ND' or 'Nicrex NDR'				
18/8/Mo	'Nicrex MC'	'Nicrex MC'	'Nicrex MC'			
23/11/W	'Nicrex HR'	'Nicrex HR'	'Nicrex HR' or 'Nicrex MC'	'Nicrex HR'	'Nicrex HR'	
16-22 Cr* 12-14 Cr*	'Nicrex ND' or 'Nicrex NDR'	'Nicrex ND' or 'Nicrex NDR'	'Nicrex MC'	'Nicrex HR'	'Nicrex HR'	
Mild Steel	'Armex 3' or 'Nicrex 1'	'Armex 3' or 'Nicrex ND'	'Nicrex MC'	'Nicrex HR'	'Armex 3'	'Armex 3'

*Require preheat 250°C. and subsequent temper to increase toughness of heat-affected zone.

MANGANESE STEEL

AUSTENITIC manganese steel, containing 11-14 per cent. manganese is used extensively where severe impact, combined with abrasion, is met.

This steel work-hardens rapidly when subject to impact, and is very suitable for applications such as crusher jaws, digger teeth, dredge bucket lips, rail-crossings, etc.

Manganese steel is non-magnetic, or feebly magnetic when cold-worked.

WELDING OF MANGANESE STEEL:

The effect on manganese steel of slow cooling from high temperatures is to embrittle it. For this reason it is absolutely essential to keep manganese steel cool during welding. This may be done by skip welding to distribute the heat, or by quenching after each run. Slow cooling from temperatures of over 300 deg. C. will embrittle the steel, and a good rule to apply is that the steel should be cool enough to touch with the bare hand before depositing another run.

Toughness may be restored to manganese steel by heating to 1060 deg. C. and quenching.

ELECTRODES RECOMMENDED BY MUREX FOR THE WELDING OF MANGANESE STEELS

For joining and building-up manganese steel, use Manganese P, Austex or Nicrex NDR, which deposit 18/8 stainless steel weld metal. Mild steel electrodes should not be used, because dilution with basis metal produces a very brittle weld.

CAST IRONS

THESE MAY be conveniently divided into the following groups:

- (a) Grey iron, which contains between 2.5 and 4 per cent. carbon, mainly in the form of flake graphite, and high silicon. This iron is relatively soft. Made by slow cooling of the casting.
- (b) White iron, of similar composition to grey iron, but having most of the carbon present in the form of intensely hard and brittle cementite, or iron carbide. The silicon content is lower. Made by rapidly cooling the casting with "chills."
- (c) Malleable irons, white heart and black heart. These are white cast irons which have been heat-treated to render them more ductile than grey irons.
- (d) Alloy cast irons. These are made for wear, corrosion and heat-resistance, and for extra strength. Examples are "Ni-Resist" (corrosion resistance), "Nicro-sil" (heat-resistance), and "Meehanite" (high tensile). Some of these cast irons contain sufficient alloys to make them austenitic.
- (e) Spheroidal graphite cast iron (S.G. iron, ductile cast iron, nodular cast iron). This is a recent development in the search for high strength cast iron. By the addition of a small amount of magnesium (generally as nickel-magnesium alloy) during tapping into the ladle the graphite is made to form in minute spheres instead of the usual flake form when the casting cools. The result is a cast iron which, in the annealed state, has mechanical properties similar to those of mild steel.

WELDING OF CAST IRONS:

All of the cast irons, except white iron, are weldable. White iron, because of its extreme brittleness,

generally cracks when attempts are made to weld it. Trouble may also be experienced when welding white-heart malleable, due to porosity caused by gas held in this type of iron.

PRECAUTIONS WHEN WELDING CAST IRONS:

The factors to consider when welding cast irons are similar, whatever the types. They are:

1. Low ductility, with a danger of cracking due to stresses set up by welding. (This is not so important when welding S.G. iron due to its good ductility.)
2. Formation of a hard, brittle zone in the weld area. This is caused by rapid cooling of molten metal to form a white cast iron structure in the weld area, and makes the weld unsuitable for service where fairly high stresses are met.
3. Formation of a hard, brittle weld bead, due to pick-up of carbon from the base metal. This does not occur with weld metals which do not form hard carbides, such as "Monel" and high nickel alloys. These are used where machinable welds are desired.

PREHEATING:

Although a large amount of satisfactory welding is done without preheating, cracking due to the rigidity or lack of ductility of castings, especially complicated shapes, may be minimised by suitable preheating.

1. Local Preheating:

Parts not held in restraint may be preheated to about 500 deg. C. in the area of the weld, with slow cooling after welding is completed.

2. *Indirect Preheating:*

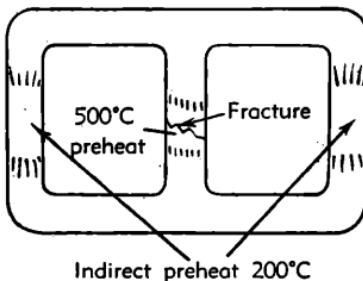
By this is meant that in addition to the local 500 deg. C. preheat, a preheat of about 200 deg. C. is given to other critical parts so that they will contract with the weld and minimise contraction stresses. Such a technique is suitable for open frames, spokes, etc. (See Fig. 73.)

3. *Complete Preheating:*

For intricate castings, especially those having varying section thicknesses such as cylinder blocks, it is advisable to completely preheat to 500 deg. C., followed by slow cooling after welding. A simple preheating furnace may be made of bricks, into which gas jets project, or filled with charcoal which burns slowly and preheats the job evenly.

PRINCIPLE OF INDIRECT PREHEATING

FIG. 73



POST-HEATING:

After any welding on cast iron, the slowest cooling possible should be allowed, the part either remaining in the preheating furnace or cooling under a blanket of insulating powder or sand. It is sometimes the practice to post-heat welded joints to relieve stresses and soften hard areas. This is done with torches or in the furnace.

PEENING:

Satisfactory welds may be made on cast iron without preheating by using electrodes depositing soft metal and peening the weld with a blunt tool (such as a ball-hammer) immediately the weld is deposited. This spreads the weld metal and counteracts the effect of contraction. Deposit short weld runs (about 2-in. at a time) and then peen before too much cooling takes place.

WELDING PROCEDURE:

Clean the area to be welded of all grease, sand, etc., before welding commences. Oil-impregnated castings should be heated to burn out all oil, otherwise porosity and poor weld bonds will result. "Gassy" castings will also produce porosity in the weld metal. This may be overcome by heating the weld area to a dull red for a short time before welding. For small components, treatment in a furnace at 650 deg. C. for 15 minutes will give fairly complete degasification.

Preheat, if necessary, to the desired temperature. If preheating is employed, use the largest electrode suitable for the job and build up the deposits to the maximum cross-sectional size. The weld is then more able to withstand stresses set up on cooling. When the casting is not preheated, use small gauge electrodes and scatter the runs to disperse the heat and cooling stresses.

To repair cracked castings, drill a hole at the end of the crack to prevent it spreading further, and grind out to the bottom. Begin welding at the drilled end of the crack, where restraint is greatest, and move towards the free end.

Castings which have to transmit fairly heavy working loads often have the weld joint assisted by mechanical means, such as bolted straps, or hoops which are shrunk on. Broken teeth on large cast iron gears are sometimes repaired by studding. Holes are drilled and tapped in the face of the fracture, and mild steel studs screwed in. These are then covered with weld metal and built up to

the required dimensions. They are afterwards machined or ground to shape.

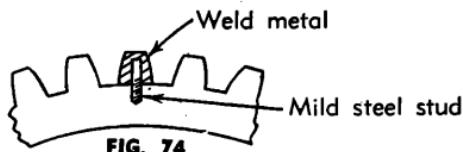


FIG. 74

nd 6th
STUDDED GEAR WHEEL TOOTH

TABLE OF GENERAL RECOMMENDATIONS

Type of Work	Electrode Recommended	
	Grey, Malleable or S.G. Cast Iron	Austenitic Cast Iron
PREHEATED 550° C. Fractures in castings through machined surfaces	CINEX, CINA	CINEX, ARMEX 2
PREHEATED 550° C. Fractures in castings (no machining of welds required)	CINEX, CINA FORTREX 35	CINEX, ARMEX 2
PREHEATED 550° C. Filling in cavities and blowholes	CINEX, CINA, FORTREX 35	CINEX, ARMEX 2
PREHEATED 550° C. Building up worn areas or broken projections	CINEX, CINA, FORTREX 35	CINEX, ARMEX 2
WELDED COLD OR LOW TEMPERATURE PRE- HEAT Fractures in thin sections	CINEX, CINA	CINEX, ARMEX 2
WELDED COLD OR LOW TEMPERATURE PRE- HEAT Fractures in heavy sections	CINEX, CINA	—
WELDED COLD OR LOW TEMPERATURE PRE- HEAT Building up worn areas	CINEX, CINA, ARMEX 2	CINEX, ARMEX 2

ELECTRODES RECOMMENDED BY MUREX FOR THE WELDING OF CAST IRON

CINEX: An electrode which has a core of high nickel content for welding with a minimum preheat. It produces an easily machinable deposit, and can be used for "buttering." Cinex can be used in all positions, and special features are the easily removable slag and neat, uniform appearance of the deposit. This electrode is not suitable for welding cast iron having a high sulphur content.

C.I.N.A.: Is an electrode depositing non-ferrous weld metal which is not hardened by carbon pick-up and hence is readily machinable.

Special Conditions:

Special conditions sometimes necessitate the use of other types of electrodes, such as stainless steel and bronze.

The Nicrex and Armex types of electrodes are often used with satisfactory results on austenitic type castings, but their application is very specialised and, therefore, information should be obtained from Murex Technical Department.

Bronze 66 and Bronze 44 electrodes are unaffected by sulphur content in the iron, a factor which may cause welds made with other electrodes to be cracked or porous. High sulphur free-cutting steel studs have been effectively welded into malleable iron hubs for automobiles. This type of electrode is also satisfactory for repairing cracks, but the machinability of the weld is not as easy as in the case of a Cinex weld. A combination of electrodes has also been used very effectively in some applications.

Bronalex 2 has been used successfully where machinability and yet high resistance to wear are essential requirements, as, for example, in the building-up of a worn surface near the flange of a cast iron wire drawing block drum.

NON-FERROUS METALS

(a) ALUMINIUM:

ALUMINIUM AND its alloys, because of their lightness, corrosion resistance and strength, are finding increasing use in chemical plant and structural work.

They are made in wrought and cast forms. The alloys may be (a) heat-treatable (containing small amounts of silicon, copper, magnesium, chromium and zinc) and obtain their strength by quenching and age-hardening, or (b) non-heat-treatable (containing mainly manganese and magnesium) and depend on cold-working for extra strength.

Welding of Aluminium:

Aluminium is very different to steel in its properties and weldability because . . .

- it has a melting point of 660 deg. C. (800 deg. C. lower than steel), but requires as much heat per pound to melt it;
- it has a thermal conductivity five times that of steel, hence heat loss is rapid, making a preheat necessary;
- it expands twice as much as steel for a given temperature increase, with greater danger of distortion;
- it forms a tough, adherent oxide film on its surface which prevents globules of molten weld from "wetting" the plate;
- it absorbs hydrogen readily when molten, but rejects it on solidification, creating a danger of porosity.

Electrodes recommended by Murex:

Murex produces a range of electrodes suitable for welding alloys of similar compositions, the most popular being "Pure Aluminium" and "Aluminium 5% Silicon."

The Murex publication M.18 may be consulted for recommendations of suitable electrodes for various aluminium alloys.

Hints for the Welder:

1. When welding all but very thin sections, use a preheat to ensure proper fusion of weld with basis metal, and insulate with asbestos felt.
2. Allow for high rate of expansion when setting up jobs. If possible, use jigs to prevent distortion, and employ frequent tack welds.
3. Design joints so that the weld has the least possible restraint placed on it to avoid hot-cracking.

Butt welds are generally stronger than fillet welds, because of more uniform stress distribution. They are also better than fillet welds in chemical plant because they are easier to clean and less likely to trap corrosive slag.

4. Keep all aluminium type electrodes in a warm, dry place, and dry at 150 deg. C. for half an hour before use.
5. Clean the surfaces of the joint with a wire brush just before welding.
6. After welding, the joints must be thoroughly cleaned with a brush and hot water to remove slag.

(b) COPPER:

Copper, and its alloys, the bronzes and brasses, are, in most cases, weldable with the arc.

1. Copper.

May be "deoxidized" or "tough pitch" copper. "Deoxidized" copper is welding quality. "Tough pitch" copper is not welded satisfactorily with the arc, due to gross porosity forming in the weld junction.

2. Bronzes:

Plain bronzes are alloys of copper and tin. Aluminium bronzes contain up to 11 per cent. aluminium, which gives high tensile strengths and excellent corrosion resistance.

3. Brasses:

Alloys of copper and zinc, with other alloys added in special cases.

Welding of Copper and Alloys:

The most important factor is the high rate of conductivity of copper, making a preheat of heavy sections necessary to give proper fusion of weld and parent metal.

It also has a high coefficient of expansion—about 35 per cent. greater than mild steel—for which allowance must be made in setting-up.

Hints for the Welder:

1. Preheat to give good fusion.
2. Insulate with asbestos sheets to prevent loss of heat.
3. When building up parts such as bronze bearings, cleanse first with petrol to remove oil, dry, and heat to drive oil from cracks.

Electrodes recommended by Murex:

For copper: Bronze 44.

For bronzes: Bronze 44 and Bronze 66.

For aluminium bronze: Bronalex 2.

For brasses: Bronze 66 and Bronze 44.

(c) NICKEL:

Nickel and high nickel alloys have excellent heat and corrosion resistance, and are easily weldable.

Nickel: Usually 99.4 per cent. pure or better. Used in chemical and food processing plant for good corrosion resistance.

Monel: Approximately 70 per cent. nickel, 30 per cent. copper. Used for corrosion resistance, e.g., marine (propellers and shafts), chemical (vats, piping, valves), food plants.

Inconel: 77 per cent. nickel, 15 per cent. chromium, 8 per cent. iron. High temperature service and corrosion resistance, e.g., pickling crates, carburizing boxes.

Nimonic: A series of alloys of approximately 75 per cent. nickel, 20 per cent. chromium, plus other elements. Used for very high temperature work, e.g., furnaces, gas turbines.

Welding of Nickel Alloys:

Welding is very similar to steel. Some high nickel alloy welds tend to crack when welded under restraint.

Lead, sulphur and phosphorous cause embrittlement. These may be picked up from grease, paints or dirt, and also preheating flames may contain sulphur gases.

Hints for the Welder:

1. Use butt joints for chemical plant; they are stronger and easier to clean.
2. Use jigs where possible to minimise distortion.
3. Use a short arc, and slower welding speed, because of rather sluggish action of nickel.
4. Preheating not generally required, providing plate temperature is not low. In this case, warm plate before welding. For intricate castings, a 100 deg. C. preheat is desirable.
5. Use sulphur-free gas for preheating.
6. Thoroughly clean joint before welding.
7. On nickel-clad material, general practice is to remove nickel from either side of the joint, weld with electrode suitable for the inner metal, and make the final overlay with electrode depositing material similar to cladding.
8. Clean slag off weld thoroughly, and for service in corrosive conditions, grind and polish to eliminate crevices.
9. Electrodes must be kept dry.

Electrodes recommended by Murex:

For Nickel: "Pure Nickel."

For Monel: "Monel."

For Inconel: Nicrex 4.

For Nimonic 75: Nicrex 4.

CUTTING BY THE ELECTRIC ARC

(cutting electrodes)

BESIDES WELDING, the arc can be used for certain other operations, such as cutting and back gouging.

The gas cutting of steel is a burning action, but steel can also be cut by a melting action, such as is provided by the metallic arc. The cut provided is rough, made use of only when other means are not available. The cutting of cast iron, stainless steel, and non-ferrous materials, however, is affected more easily with the arc, unless the powder cutting process is available.

If cutting electrodes are properly used, no metal will be deposited; the slag and surplus metal can be readily knocked off leaving a fairly clean cut, but much wider than that usually made with the oxy-acetylene torch.

High current is essential; cutting should, where possible, be commenced on the edge of the plate and the arc played up and down on edge of the cut. The electrode should be held at an acute angle to the plate.

As opposed to the use of the electrode when welding, a long arc should be drawn which is rendered possible by the high current used; this will cause the molten metal to run down the cut and should be followed up by feeding in the electrode quickly up and down through the thickness of the plate.

To cut a section from a plate, a hole is first blown through by concentrating the arc at a predetermined spot and then forcing down until the arc blows through the plate (this can be done equally well either in the horizontal or vertical position); the hole can then be enlarged or extended into a cut if required. The blowing of holes requires a little practice, but once the technique is acquired will present no difficulties to the operator.

Arc cutting cannot compete with oxy-acetylene either in speed or cost, and it is only intended for emergency use when gas equipment is not available.

Cutting electrodes may be used with either A.C. or D.C.

BACK GOUGING:

Before welding the other side of joints which must have 100 per cent. penetration, it is necessary to remove the unfused metal as well as any defective weld metal deposited on the first side—this may be done by machining, chipping, or by back gouging with the oxy-acetylene or the metallic arc.

If the metallic arc is used by an experienced operator a very satisfactory welding groove can be obtained much more quickly than by chipping.

This is particularly true if a large amount of metal must be removed; a very suitable electrode for this application is the Murex "Deepex."

The electrode can be used by pointing it in the direction of the line of groove at an angle of 5 deg, to the surface of the material—normal current and steady pressure applied during the operation of grooving.

Contex electrodes are also very suitable for cutting.

HARDFACING

THE PROCESS of covering wearing areas with wear-resistant metal by welding is known as hardfacing.

It has a wide application in all fields of industry, and its intelligent use results in longer, more efficient machine life, less down time and less maintenance costs.

It is becoming common practice to make wearing parts of cheaper steels and to hardface the wearing areas, thus conserving expensive alloy steels, and still obtaining results that are as good or better than these steels give. Stainless steel overlays on mild steel for corrosion resistance are often employed.

TYPES OF WEAR:

There are two main types of wear.

1. *Shock or Impact:*

The material to resist this kind of wear must be hard enough to resist serious deformation, and yet not so hard as to be brittle and crack under the effect of impact. Electrodes depositing such metal are:

- 1 (a) Austex and Manganese P, both of which work-harden under impact. These metals are very ductile and do not easily crack.
- (b) Hardex 250 and Hardex 350, the deposits of which do not work-harden appreciably, but which are fairly hard and sufficiently ductile to resist cracking. They will not, however, withstand severe impact, since they tend to deform under the blows. Hardex 350 is better able to resist this than Hardex 250.

The best solution to the problem of resisting very severe impact may be to employ a buffer layer of Austex, followed by a layer of Hardex 650 or 350.

Hardex 650 alone, although depositing a very hard alloy, is suitable for moderate impact conditions.

2 Abrasion:

This is caused by a grinding action of particles against the wearing surfaces, or by rubbing together of surfaces. To resist this type of wear, a relatively hard material is needed, and it often happens that this material is also somewhat brittle and unable to withstand severe impact without cracking. The Murex electrodes Hardex 800, Hardex 650, and Tubex give hard deposits suitable for withstanding abrasion under various conditions.

It is very seldom that either of these two types of wear is found alone; generally both are present in greater or lesser degree, and it is a question then of selecting an electrode that will most satisfactorily cope with both conditions.

Added to these types of wear it sometimes happens that the part in question is also operating under corrosive conditions, and a hardfacing alloy that is able to resist this must be used.

The foregoing brief account gives some idea of the range of conditions likely to be met. For specific applications, the Murex Technical Staff is always willing to offer advice.

PREHEATING:

There are four main reasons for preheating parts to be hardfaced:

1. To prevent underbead cracking of steels having sufficient carbon or alloys to make them very hardenable.
2. To prevent cracking of rigid, brittle components due to contraction of the weld metal.
3. To prevent cracking of large areas of the very hard types of hardfacing.
4. To minimise distortion of the part being welded.

The first point is the most important to watch, since a large amount of hardfacing is done on medium-to-high carbon and alloy steels, and if underbead cracks form the weld deposit may spall off in service.

The importance of the other points mentioned depends on the particular application in hand.

ELECTRODES RECOMMENDED BY MUREX FOR HARDFACING APPLICATIONS

HARDEX 250: An electrode depositing chromium steel weld metal of hardness between 230 and 280 V.P.N. On alloy and high carbon steels this hardness may be higher. Useful for repairing carbon steel rails, building-up worn shafts, idler wheels, track links, sprockets, etc.

HARDEX 350: A similar electrode to Hardex 250, but depositing chromium-molybdenum steel of hardnesses between 320 and 450 V.P.N., depending on base metal. Used for building-up idler wheels, track links, rotary hoe blades.

HARDEX 450: A low hydrogen electrode for minimizing hard zone cracking on hardenable steels. Useful on a wide variety of earth moving equipment. Hardness of weld metal is 450 V.P.N.

HARDEX 650: An electrode depositing an air-hardening chromium-molybdenum steel possessing very good wear resistance. Hardness on mild steel is 600-700 V.P.N. Used where abrasion is severe and where reasonable impact strength is necessary, such as dozer blades and grouser tips (using Austex or Fortrex 35 buffer), bucket teeth, crusher jaws, shear blades, dies.

HARDEX 800: An electrode depositing highly-alloyed weld metal for resisting very severe abrasion. As-welded hardness 750-850 V.P.N. Used as a final hard-facing layer on bucket teeth, crusher jaws, grader blades, concrete mixer blades, pug mill knives, brick mould linings.

AUSTEX: A smooth-running electrode depositing 18/8 stainless steel weld metal. The alloys are contained in the coating and because of this the rate of deposition is fast. The weld metal work-hardens rapidly, while retaining a tough core, making it suitable for conditions of severe impact. Used also as a buffer between hard-facing layers and hardenable steels. Common buffer applications are grouser plates, dozer blades, crusher jaws, etc. Also useful for building up on manganese steel, for gear teeth, cams, etc. Has very good corrosion resistance.

MANGANESE P: Similar to Austex in its application, but the core wire of the electrode is stainless steel.

TUBEX: A tubular electrode containing intensely hard tungsten carbide particles, useful for combating the severest abrasion, such as oil drill bits and collars, pug mill knives, scarifier teeth, etc.

HARDEX CHR: A nickel-base austenitic electrode possessing excellent corrosion and high temperature scaling resistance. Used for valve seatings, coke pusher rods, roll mill guides.

HARDEX T: This is designed for producing turning and other machine tools by tipping mild or medium carbon steel shanks. The high alloy weld metal gives superior life to the standard 18/4/1 type. Hardness up to 1000 V.P.N. is developed by suitable heat treatment; this is retained up to red heat.

TECHNIQUES FOR SELECTED APPLICATIONS

GROUSER PLATES

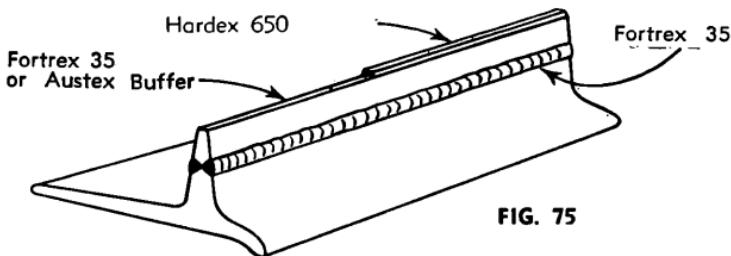


FIG. 75

New or Slightly Worn Grousers:

Cover the working edge with one run of Austex or Fortrex 35 to act as a buffer. Hardface with one run of Hardex 650. Do NOT apply hardfacing direct to grouser. Use step back sequence in 6-in. runs to reduce distortion.

Badly Worn Grousers:

Flame cut the tip to a straight edge and weld on build-up strip of mild steel or special carbon steel with Fortrex 35, again using step back sequence. Allow sufficient gap for complete penetration.

Mild steel may be hardfaced with Hardex 650 direct. Special steel strip requires buffer of Austex or Fortrex 35 before hardfacing.

TRACK LINKS

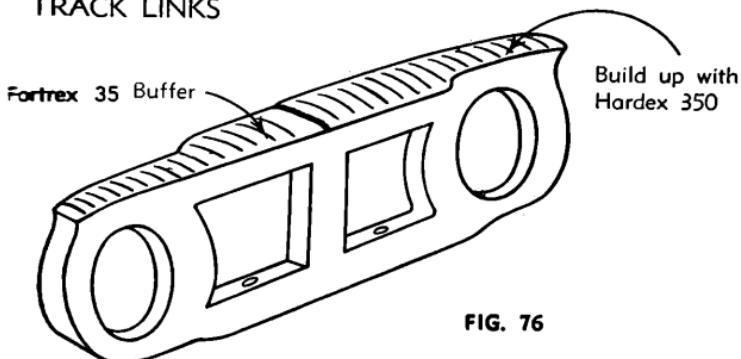


FIG. 76

Track Links:

Because of high carbon content of steel, it is desirable to use buffer of Fortrex 35 or Austex for first layer. If Austex is used, no other hardfacing is necessary, since this deposit work-hardens to over 400 V.P.N.

Hardex 350 is used to build up over Fortrex 35.

If it is convenient, a preheat of 150 deg. C. may be used and Hardex 350 applied direct to link. In any case, it is an advantage to warm the side of the link opposite the one being welded to counteract the effect of contraction.

A jig, made up of copper bar, is of great assistance in securing desired shape of weld deposit.

IDLER WHEEL

Fortrex 35 Buffer
followed by
Hardex 250
or Hardex 350

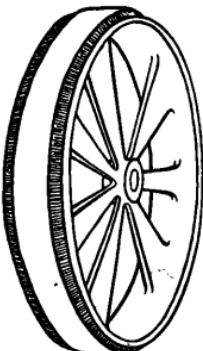


FIG. 77

Idler Wheel:

Mount the wheel on a shaft for easy manipulation. Weld diametrically opposed segments to reduce distortion. Use Fortrex 35 for first layer and hardface with Hardex 250 or Hardex 350. Alternatively, use Austex alone for all building-up and hardfacing.

DRIVE SPROCKET
TEETH

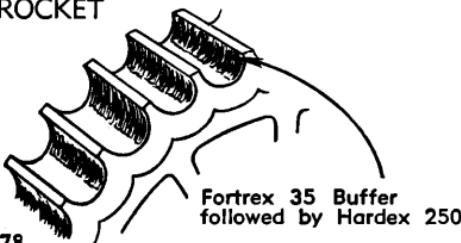


FIG. 78

Drive Sprocket Teeth:

Cut a steel template, patterned from a new wheel, covering three or four teeth. The weld deposit can then be checked to see when there is sufficient build-up.

Fortrex 35 is used for the first layer to ensure freedom from cracking, and the remaining build-up is done with Hardex 250. Alternatively, Austex may be used for all the build-up.

TRACK ROLLERS

Fortrex 35 Buffer
followed by Hardex 250
or Hardex 350

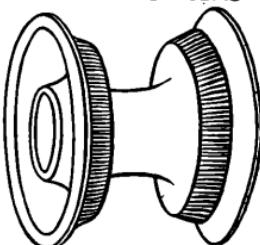


FIG. 79

Track Rollers:

Generally made of cast steel and flame or induction hardened on the wearing surface.

Method: Mount on shaft for easy turning. Use Fortrex 35 for first run, and Hardex 250 or Hardex 350 for build-up.

Top rollers are sometimes made of cast iron with white iron wearing surfaces, and are often considered not worthwhile reclaiming. If it is desired to build up these rollers, use two layers of Fortrex 35 followed by Hardex 250 or Hardex 350. Preheat to 500 deg. C. before welding commences.

DOZER BLADE TIPS AND WEARING STRIPS

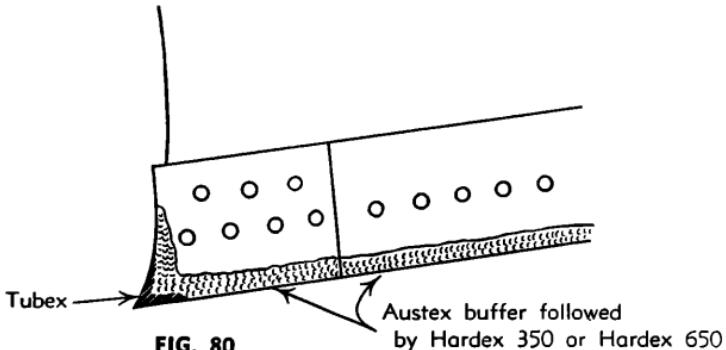


FIG. 80

Dozer Blade Tips and Wearing Strips:

These are made of high carbon steel and it is essential to use a buffer layer.

Method: Preheat the blades to 150 deg. C. before welding. For blades working under heavy impact as well as abrasion, use Austex buffer layer on all surfaces to be hardfaced, followed by Hardex 350 or Hardex 650.

For abrasive wear only, as in sand or clay pits, Fortrex 35 followed by Hardex 650 is suitable.

A layer of Tubex on the corner of the tip greatly helps in preventing this from becoming rounded.

SCARIFIER AND DITCHER TEETH

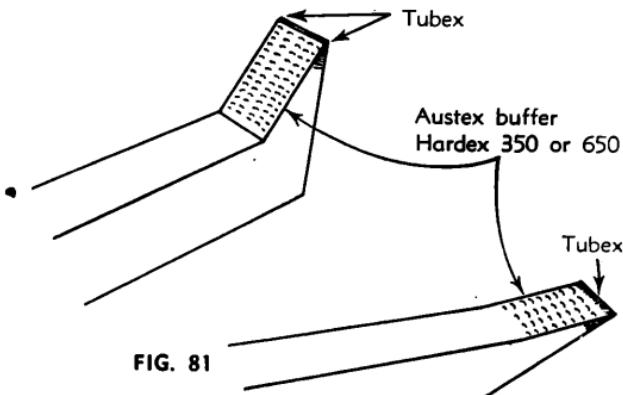


FIG. 81

Scarifier and Ditcher Teeth:

Worn Manganese Steel Teeth: Build up with Austex and hardface with Hardex 650 or Hardex 350. Do not allow to overheat.

New Manganese Steel Teeth: One layer of Hardex 350 or Hardex 650.

High Carbon Steel Teeth: Austex for build-up or buffer. Hardex 350 or Hardex 650 for hardfacing.

A deposit of Tubex on the corners prolongs tooth life.

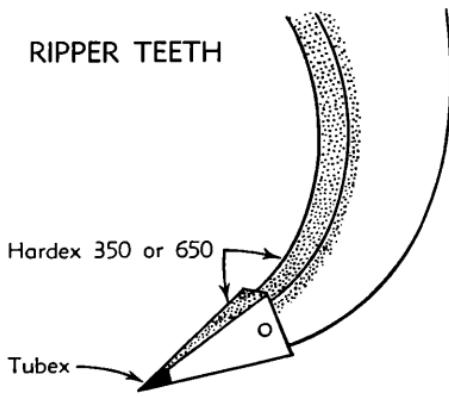


FIG. 82

Ripper Teeth:

Generally made of manganese steel. Use Hardex 650 or if building-up needed, use Austex, with final layer of Hardex 350. Do not allow manganese steel to overheat.

Tubex on the point will give extended life.

If teeth are made of high carbon steel, apply Austex buffer before hardfacing.

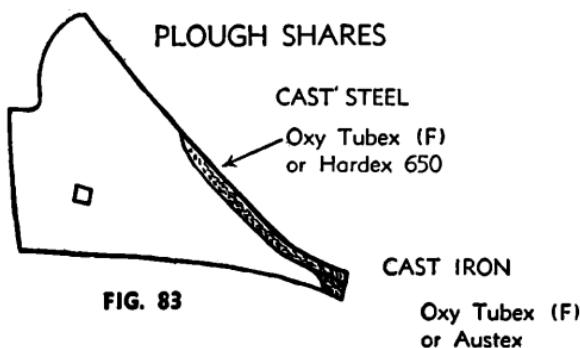


FIG. 83

Ploughshares:

It is always best to hardface ploughshares before use or when only a little wear has taken place.

Cast Iron Ploughshares: Use oxy-Tubex (Grade F) on clean surface, or use small gauge Austex in short runs.

Cast Steel Ploughshares: Use oxy-Tubex (Grade F) or Hardex 650.

Only one face of the share requires hardfacing in order to create a self-sharpening edge.

EXCAVATOR BUCKETS

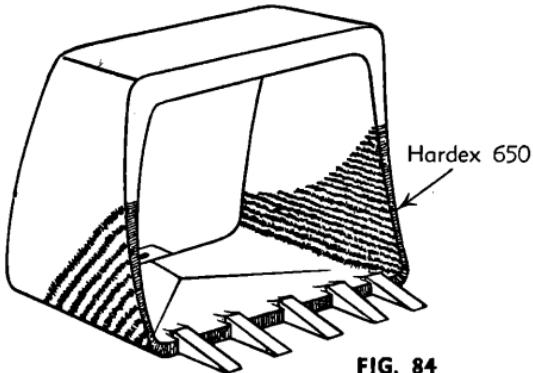


FIG. 84

Excavator Buckets:

Deposit runs of Hardex 650 at distances of 1-2 inches apart on all wearing faces. Cover all rivet heads with Hardex 650, otherwise they wear away very rapidly.

EXCAVATOR TEETH

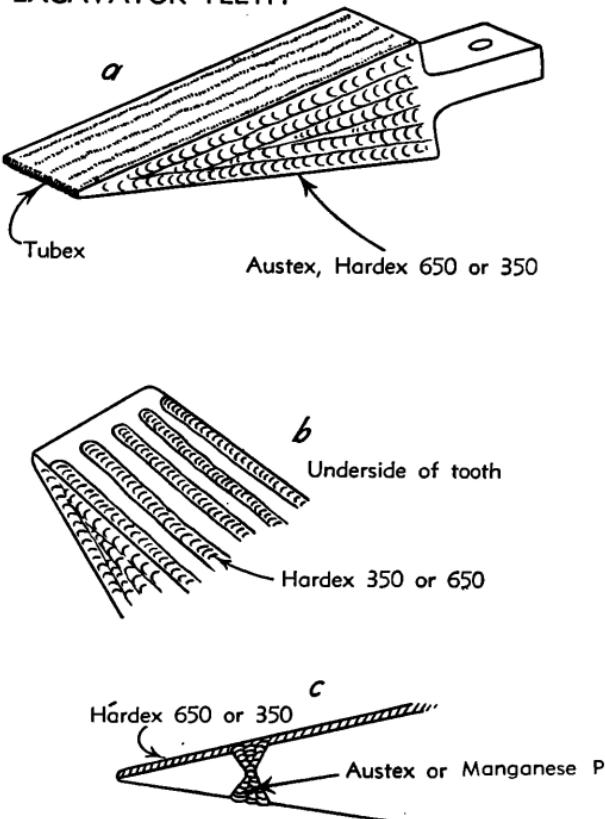


FIG. 85

Excavator and Bucket Teeth:

If these are made of manganese steel, use Hardex 650 or Hardex 350. Manganese steel must not overheat or it becomes brittle; therefore, scatter the welds or quench to keep cool. If building-up needed, use Austex before hardfacing.

For teeth made of high carbon steel, use Austex buffer, followed by Hardex 650 or Hardex 350. Provide a self-sharpening edge by covering the upper surface with hardfacing, and depositing stringer beads on the underside. The softer base metal wears more rapidly than the hardfacing, thus maintaining a sharp edge, but stringer beads prevent excessive wear. (See Fig. 85b.)

If teeth are badly worn, new steel tips are welded on with Austex or Manganese P and hardfaced, as shown in Fig. 85c.

EXCAVATOR DOOR

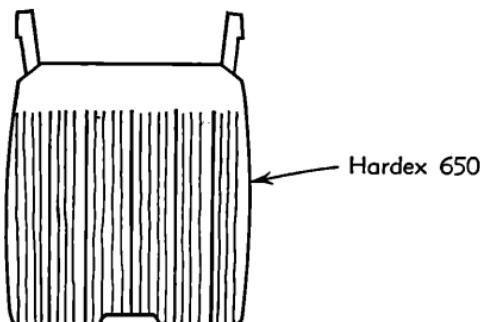


FIG. 86

Excavator Door:

Deposit runs of Hardex 650 at 1-in. intervals as shown in the sketch.

PUMP IMPELLORS

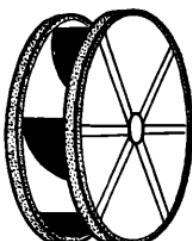
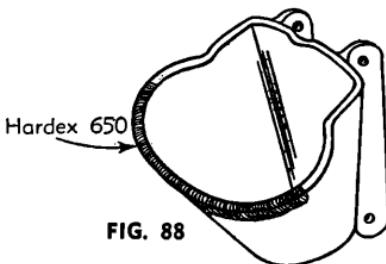


FIG. 87

Pump Impellers:

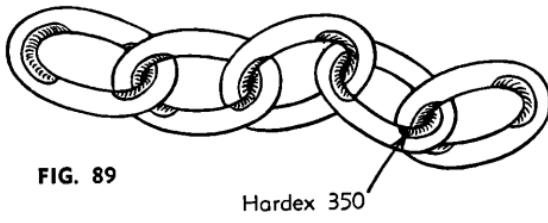
Hardface with Hardex 650 or Hardex 800 as shown. Use small electrodes to keep heat input down. The pump casings may also be hardfaced with Hardex 650 or Hardex 800 if not made of cast iron. If castings are cast iron, use Cinex or CINA for building-up.

DREDGE BUCKET LIPS



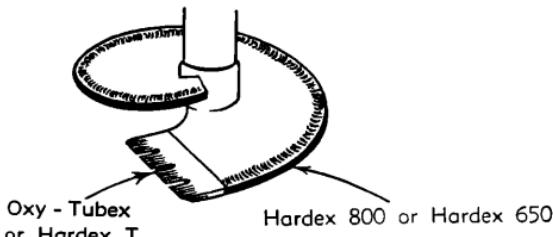
Dredge Bucket Lips:
Hardface lips with Hardex 650.

CHAINS



Chains (Dragline, etc.):
Hardface wearing areas with Hardex 350.

POST HOLE AUGER



Post Hole Auger:

The cutting edge gives best service if hardfaced with Tubex (Grade F) (oxy-acetylene). Only the upper cutting surface and corners need to be hardfaced, thus providing a self-sharpening edge.

The edges of the spiral may be hardfaced with Hardex 800 or Hardex 650 as shown in Fig. 90.

COAL CUTTER PICKS

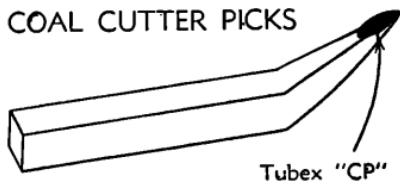


FIG. 91

Coal Cutter Picks:

Tubex CP has been specially designed for this application. Deposited by oxy-acetylene welding. The tube contains tungsten carbide granules and a special flux enabling a small deposit to be placed on the tip. This ease of deposition can be best utilised if a number of picks are lined up in a jig with the surface to be hardfaced held horizontal.

DRILL BITS

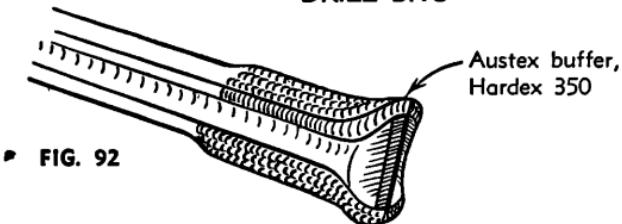


FIG. 92

Drill Bits:

Preheat to 200 deg. C. and apply Austex buffer. Hardface with Hardex 350 or Hardex 650. Build the corners out so that drill will not stick in hole.

OIL DRILL BITS (FISH TAILS)

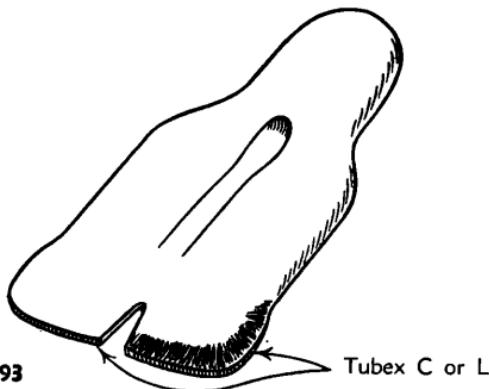


FIG. 93

Tubex C or L

Oil Drills (Fish Tails):

Clean the surface to be welded. Apply oxy-Tubex (C or L) to the wearing edge as shown in the sketch.

When using oxy-Tubex, use a carburizing flame and heat the surface until it just begins to "sweat." Then melt the Tubex rod on to this surface with a slight weaving motion to distribute carbide. Do not keep weld deposit molten too long or carbide settles to bottom.

OIL DRILL JOINTS AND COLLARS

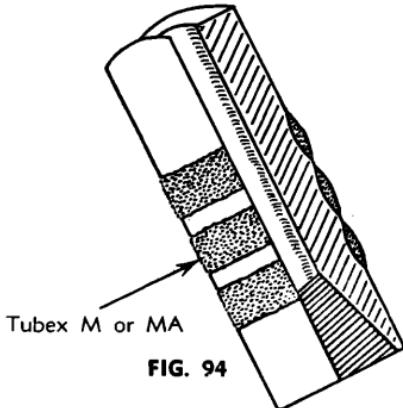
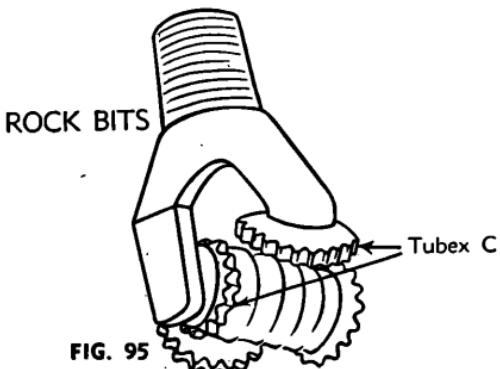


FIG. 94

Oil Drill Collars and Joints:

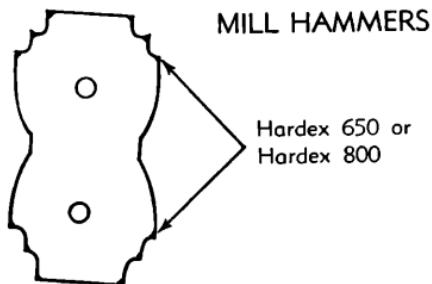
Oxy-Tubex M or Arc-Tubex MA is deposited in bands around collars and joints as shown in Fig. 94, and built out slightly beyond the rest of the metal to give adequate protection.



Rock Bits:

Oxy-Tubex on the teeth of rock bits greatly prolongs life. The grade used depends on the rock being drilled, but C and L are commonly used.

Use welding technique described for "fish tails."



Mill Hammers:

Preheat to 250 deg. C. Build up worn corners with Hardex 650 or Hardex 800.

CONVEYOR SCREWS

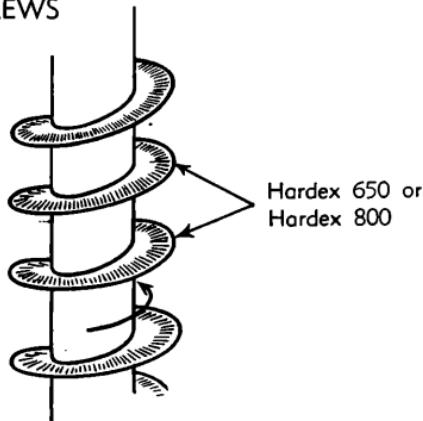


FIG. 97

Conveyor Screws:

Mount the screw on a shaft for easy turning. Deposit Hardex 650 or Hardex 800 on the edge and bearing surface of the screw.

For cast iron screws, use Austex or Fortrex 35 deposited in short runs from small gauge electrodes. Hardfacing is generally confined to the edge of the spiral due to the brittleness of cast iron.

CRUSHER JAWS

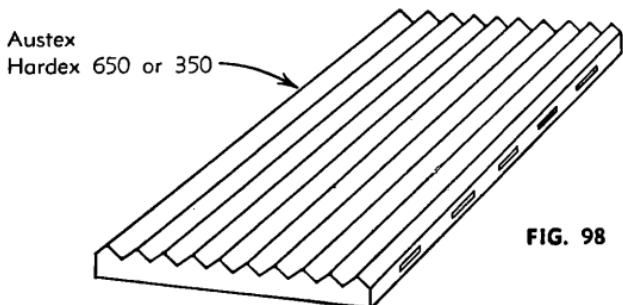


FIG. 98

Crusher Jaws:

Usually made of manganese steel. If so, build up with Austex and hardface with Hardex 650 or Hardex 350, with usual cooling precautions, i.e., scattered welds, or quenching.

If made of high carbon or alloy steel, buffer with Austex and hardface with Hardex 350, Hardex 650 or Hardex 800, using step-back sequence to reduce distortion.

GRIZZLIES

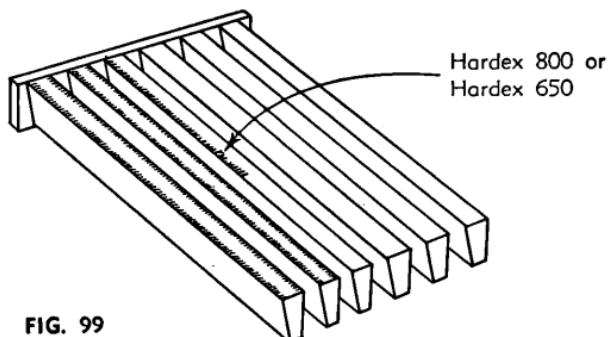
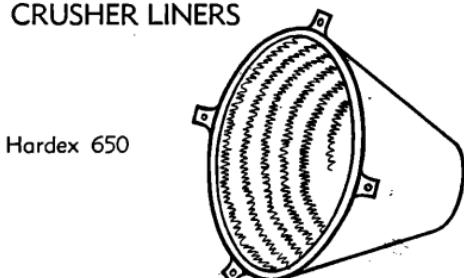


FIG. 99

Grizzlies:

Use Hardex 800 or Hardex 650 along the wearing edges of the bars. If necessary, deposit a run also in the centre of the bars.

CRUSHER LINERS



Hardex 650

FIG. 100

Crusher Liners:

May be manganese steel. If so, hardface with Hardex 650 or Hardex 350, observing usual cooling precautions. Deposit runs as shown in sketch.

For building-up, use Austex before hardfacing.

CRUSHER MANTLES

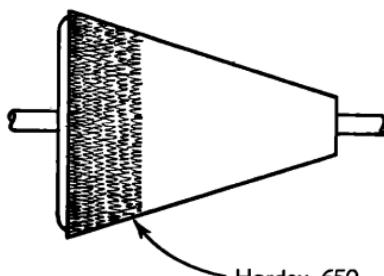


FIG. 101

Hardex 650

Crusher Mantles:

For building up on carbon steel, use Hardex 250 or Hardex 350, followed by Hardex 650.

For building up on manganese steel, use Austex and hard-face with Hardex 350 or Hardex 650.

CYCLONE FAN BLADES

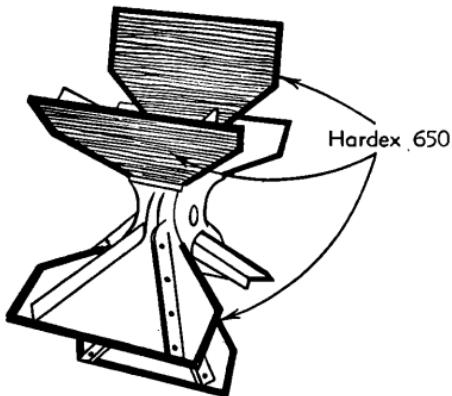


FIG. 102

Cyclone Fan Blades:

Use Hardex 650. It is essential that the contact sides be completely covered with hardfacing and that the runs be even and completely overlap, because abrasion will quickly enlarge any depression.

After welding, balance the blades by grinding off heavy portions.

PUG MILL KNIVES

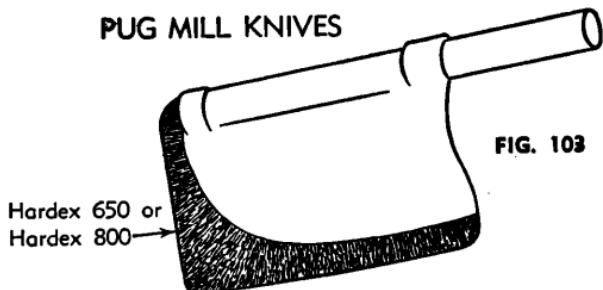


FIG. 103

Pug Mill Knives:

More economical to hardface when only a little wear has taken place. Use Hardex 800 for long-wearing, or Hardex 650. If building-up necessary, use Hardex 350 and then hardface with Hardex 800 or Hardex 650.

BEATER BAR (SWARF HAMMER)

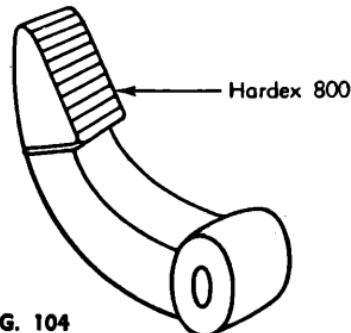
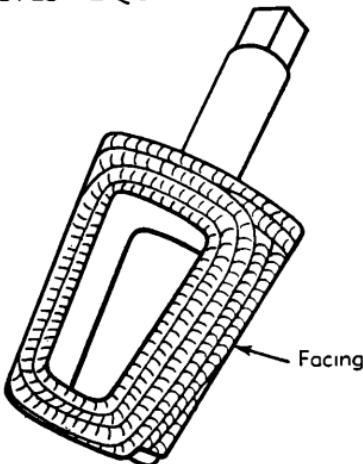


FIG. 104

Beater Bar (Swarf Hammer):

Use Hardex 800. Set face of hammer in mould, preheat to 500 deg. C. and cover with hardfacing, using wide weave.

VALVES (LIQUID)



Valves (Liquid):

The electrode to be used depends on the material in the valve. For bronze valves use Bronalex 2; for 18/8 stainless steel use Nicrex MC or Nicrex NDR; for cast iron use Cinex or

FIG. 105.

Nicrex 4; for steel use electrode suitable to resist corrosion being met. For mild corrosive conditions, Bronalex 2 on steel is suitable; for more severe corrosion use Nicrex NDR.

After building up as shown in the sketch, machine or grind to shape.

VALVES AND SEATS (LIQUID AND STEAM)

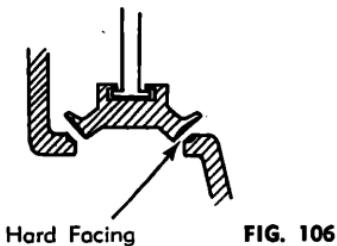


FIG. 106

Valves and Seats (Liquid and Steam):

Machine grooves in valve and seat. Deposit weld with suitable sized electrode, making sure there is sufficient build-up to allow for machining back to desired shape.

Electrodes used will depend on composition of basis metal (see recommendations for Valves above).

Use Hardex CHR for resisting attack by corrosive liquids at high temperature, and liquids carrying abrasive material.

VALVE SEATING (I. C. ENGINE)

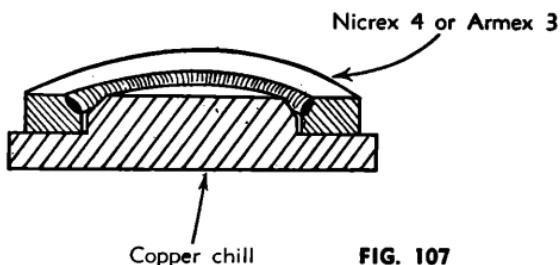


FIG. 107

Valve Seating (I.C. Engine) :

Machine out groove in valve seat to take weld deposit. A copper chill shaped as in Fig. 107 helps to prevent excessive melting of seat, and to retain shape of bead. Use small gauge Armex 3 or Nicrex 4 at low amperage.

VALVES (I. C. ENGINE)

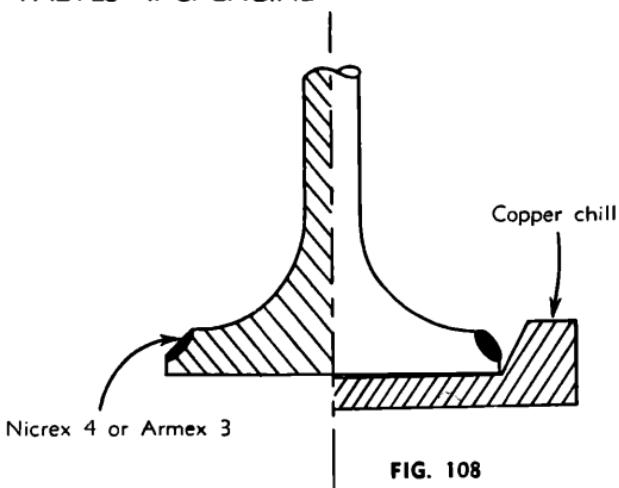


FIG. 108

Valves (I.C. Engines) :

Machine groove in seating edge and place valve in copper chill (see Fig. 108). Use small gauge Armex 3 or Nicrex 4, at low amperage so as not to melt edge of valve away.

GEAR TEETH

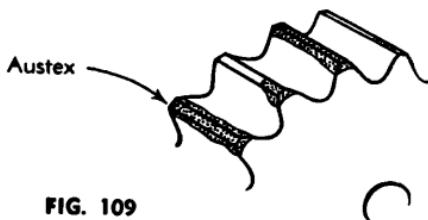


FIG. 109

Gear Teeth:

For repairing broken and chipped gear teeth, use Austex. On large gears a slight preheat is desirable. The deposit may be machined back to the desired contour.

CHISELS

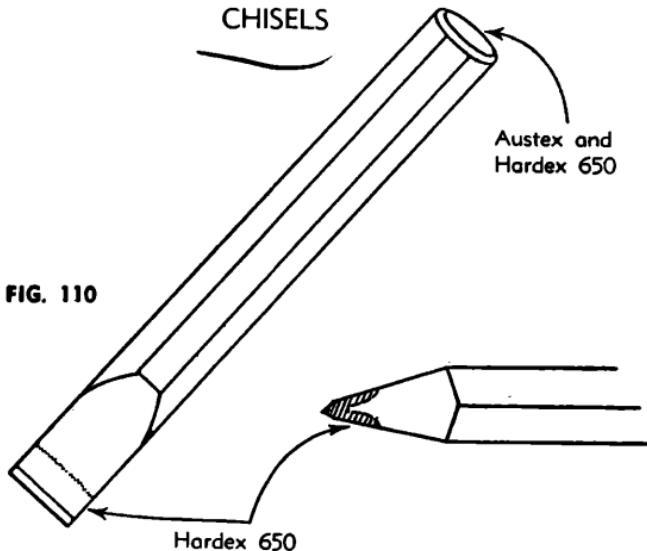


FIG. 110

Chisels:

Chisels may be re-tipped with Hardex 650 and striking end hardfaced with Austex buffer followed by Hardex 650. This is very successful in overcoming "mushrooming". New chisels may be made from mild steel bar using the technique described.

TOOL TIPS

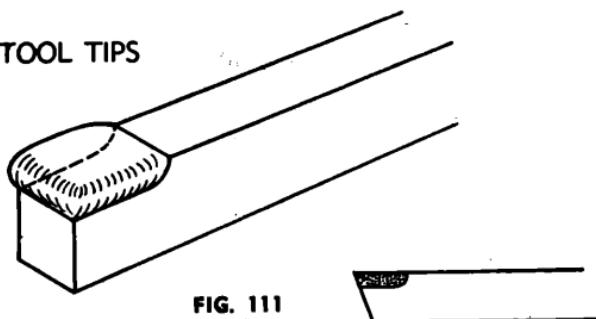


FIG. 111

Tool Tips:

Very satisfactory lathe tools may be made up using a mild or low alloy steel shank with a Hardex T deposit for the cutting edge. The supporting parent metal beneath the bead should be at least twice the thickness of the Hardex T deposit to give adequate strength.

Make a mould of copper, carbon or a suitable plastic refractory material to retain the molten deposit on the tip. Puddle the weld metal into the mould until build-up is sufficient and allow to cool in air. Deposit is self-hardening.

SHEAR BLADES

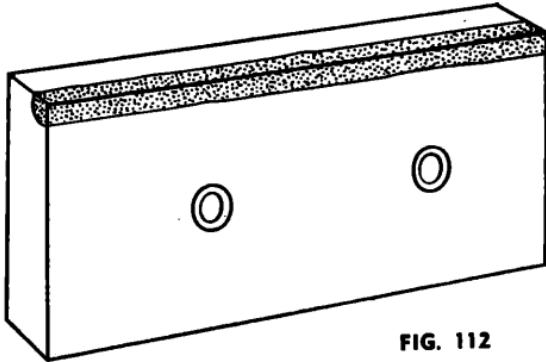


FIG. 112

Shear Blades:

A groove is machined on the cutting edge as shown. Blades may be made of mild steel, or a carbon or alloy steel, in which case a preheat is needed, the amount depending on the carbon or alloy content.

To avoid distortion in long blades either bolt blades back to back or hold in a suitable restraining jig, and use the step-back sequence of deposition.

Building-up should be done with Hardex 350 and the final hardfacing with Hardex 650.

AXLES AND SHAFTS

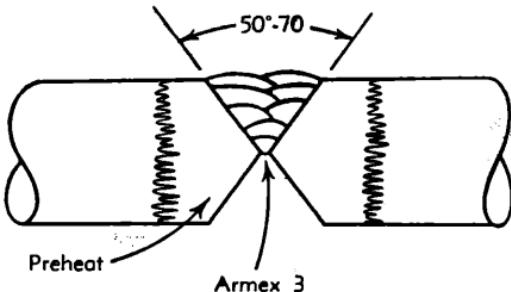


FIG. 113

Axles and Shafts:

Prepare the broken ends to chisel points to give an included angle of 50-70 deg. Set up pieces in a jig to give proper alignment.

Preheat is sometimes needed, depending on the type of steel, but 100 deg. C. is usually safe. Weld with Armex 3, balancing the sequence of welding on either side as much as possible to cancel out effects of contraction.

Fortrex 35 is sometimes used instead of Armex 3, in which case a 200 deg. C. preheat is usually needed.

SPRINGS

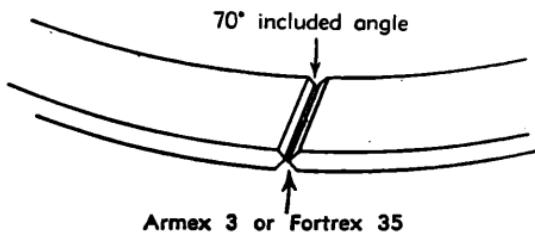
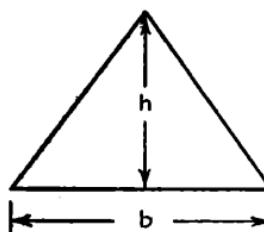


FIG. 114

Springs:

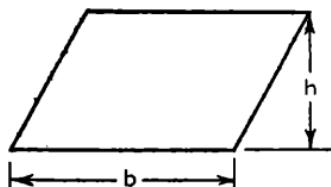
Prepare a 70 deg. included angle on the broken ends, line up the pieces, and weld with Armex 3. Fortrex 35 may also be used, in which case a 100 deg C. preheat is desirable.

MENSURATION



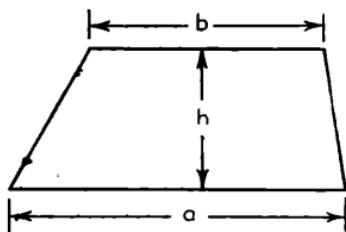
TRIANGLE

$$\text{Area} = \frac{b \times h}{2}$$



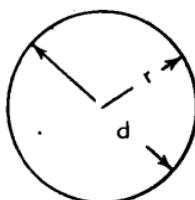
PARALLELOGRAM

$$\text{Area} = b \times h$$



TRAPEZOID

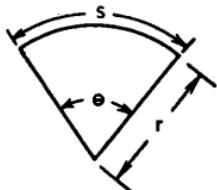
$$\text{Area} = \frac{1}{2}(a+b) \times h$$



CIRCLE

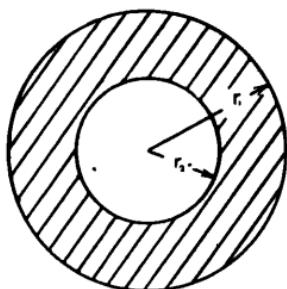
$$\text{Area} = \pi r^2 \text{ or } \frac{\pi d^2}{4} \text{ (or } \frac{11}{14} \times d^2\text{)}$$

$$\text{Circumference} = 2\pi r = \pi d$$



SECTOR

$$\text{Area} = \frac{\pi r^2 \times \theta}{360} \text{ or } \frac{s \times r}{2}$$

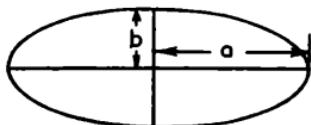


ANNULUS

$$\text{Area} = \pi(r_1 + r_2)(r_1 - r_2)$$

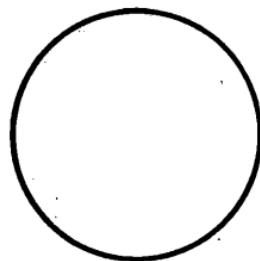
(Circles need not be concentric
for this rule to apply.)

ELLIPSE



$$\text{Area} = \pi a b$$

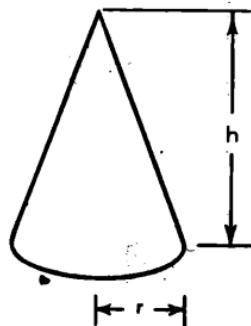
$$\text{Circumference} = 2\pi\sqrt{\frac{a^2 + b^2}{2}}$$



SPHERE

$$\text{Area} = 4\pi r^2 = \pi d^2$$

$$\text{Volume} = \frac{4}{3} \times \pi r^3 = \frac{\pi d^3}{6}$$

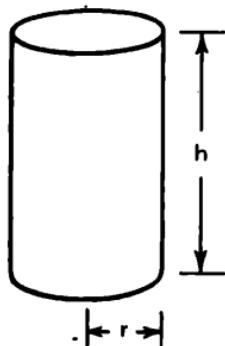


CONE

Area of curved surface

$$= \pi r \sqrt{r^2 + h^2}$$

$$\text{Volume} = \frac{\pi r^2 h}{3}$$



CYLINDER

Area of curved surface

$$= 2\pi r h$$

$$\text{Volume} = \pi r^2 h$$

$$(\pi = 3.1416 = \frac{22}{7} \text{ approx.})$$

CROSS-SECTIONAL AREAS OF ELECTRODE DEPOSITS

Length of Weld per Elec- trode	Cross- sectional Area of Electrode Deposits		Length of Weld per Elec- trode	Cross- sectional Area of Electrode Deposits		Length of Weld per Elec- trode	Cross- sectional Area of Electrode Deposits		
	Gge./in.	Sq.in.	Sq.mm.	Gge./in.	Sq.in.	Sq.mm.	Gge./in.	Sq.in.	Sq.mm.
12/4	-035	22.61	8/17	-020	12.59	18.9	1/14	.141	90.69
12/5	-028	18.09	8/18	-018	11.89	18.10	1/12	.127	81.63
12/6	-023	15.08				18.11	1/12	.115	74.21
12/7	-020	12.93	6/6	-080	51.37	18.12	1/13	.105	68.02
12/8	-018	11.31	6/7	-068	44.03	18.13	1/14	.097	62.79
12/9	-016	10.05	6/8	-060	38.53	18.14	1/15	.090	58.31
12/10	-014	9.05	6/9	-053	34.24	18.15	1/16	.084	54.42
12/11	-013	9.22	6/10	-048	30.82	18.16	1/17	.079	51.02
12/12	-012	7.54	6/11	-043	28.02	18.17	1/18	.074	48.02
12/13	-011	6.96	6/12	-040	25.68	18.18	1/19	.070	45.35
12/14	-010	6.45	6/13	-037	23.71	18.19	1/20	.067	42.96
			6/14	-034	22.01	18.20	1/21	.063	40.81
10/4	-053	34.24	6/15	-032	20.55	18.22	1/22	.058	37.10
10/5	-042	27.39	6/16	-030	19.27	18.24	1/23	.053	34.01
10/6	-035	22.83	6/17	-028	18.13	18.26	1/24	.049	31.39
10/7	-030	19.56	6/18	-027	17.12	18.28	1/25	.045	29.15
10/8	-027	17.12	6/19	-025	16.22				
10/9	-024	15.22	6/20	-024	15.41				
10/10	-021	13.69				1/9	.202	130.55	
10/11	-019	12.45	4/8	-087	56.23	1/10	.182	117.49	
10/12	-018	11.42	4/9	-077	49.99	1/11	.166	106.81	
10/13	-016	10.53	4/10	-070	44.99	1/12	.152	97.91	
10/14	-015	9.78	4/11	-063	40.89	1/13	.140	90.38	
			4/12	-058	37.49	1/14	.130	83.92	
			4/13	-054	34.60	1/15	.121	78.33	
8/6	-055	35.67	4/14	-050	32.13	1/16	.114	73.43	
8/7	-047	30.57	4/15	-047	30.00	1/17	.107	69.11	
8/8	-041	26.76	4/16	-044	28.12	1/18	.101	65.27	
8/9	-037	23.78	4/17	-041	26.46	1/19	.096	62.18	
8/10	-033	21.40	4/18	-039	24.99	1/20	.091	58.75	
8/11	-030	19.46	4/19	-037	23.68	1/22	.083	53.41	
8/12	-028	17.83	4/20	-035	22.49	1/24	.076	48.96	
8/13	-026	16.47	4/22	-032	20.45	1/26	.070	45.15	
8/14	-024	15.29	4/24	-029	18.74	1/28	.065	41.96	
8/15	-022	14.27				1/30	.061	39.17	
8/16	-021	13.38				1/32	.057	36.72	

Note.—The above figures have been calculated for a standard 18 in. electrode, with an allowance of $1\frac{1}{2}$ in. for discarded ends. A further deduction for welding losses will have to be made for each type of electrode.

WELD DATA PER FOOT RUN

Fillet Welds

Lth. of Leg in.	Throat Thknss. in.	Area sq.in.	Vol. cu.in.	Wt. lb.	Lth. of Leg in.	Throat Thknss. in.	Area sq.in.	Vol. cu.in.	Wt. lb.
$\frac{1}{8}$	.088	.012	.138	.039	$\frac{1}{4}$	.354	.140	1.676	.474
$\frac{3}{16}$	.133	.023	.277	.078	$\frac{1}{4}$	.441	.213	2.561	.725
$\frac{1}{4}$	.176	.039	.463	.131	$\frac{1}{4}$	.530	.303	3.641	1.030
$\frac{5}{16}$	.221	.058	.697	.197	$\frac{1}{4}$	.618	.409	4.903	1.388
$\frac{3}{8}$	.265	.081	.976	.374	$\frac{1}{4}$	.707	.529	6.348	1.796

Figures shown allow for $\frac{1}{2}$ in. thickness of reinforcement.

Single Butt

Plate Thick-ness in.	Gap in.	60° Butt			70° Butt		
		Area sq.in.	Vol. cu.in.	Wt. lb.	Area sq.in.	Vol. cu.in.	Wt. lb.
$\frac{1}{8}$	$\frac{1}{2}$	.017	.199	.056	.019	.229	.065
$\frac{3}{16}$	$\frac{1}{2}$	.031	.372	.105	.037	.439	.124
$\frac{1}{4}$	$\frac{1}{2}$	.051	.606	.172	.060	.714	.202
$\frac{5}{16}$	$\frac{1}{2}$	.075	.900	.255	.088	1.055	.299
$\frac{3}{8}$	$\frac{1}{2}$	.118	1.412	.340	.134	1.609	.455
$\frac{1}{2}$	$\frac{1}{2}$	.189	2.263	.641	.222	2.666	.755
$\frac{5}{16}$	$\frac{1}{2}$	.302	3.619	1.024	.352	4.226	1.196
$\frac{3}{8}$	$\frac{1}{2}$	.414	4.972	1.407	.488	5.855	1.657
$\frac{7}{16}$	$\frac{1}{2}$	.547	6.565	1.858	.645	7.746	2.192
$\frac{1}{2}$	$\frac{1}{2}$	.697	8.361	2.366	.825	9.901	2.802

Figures shown allow for $\frac{1}{2}$ in. thickness of reinforcement.

Scaling run for single butts = $1 \times 10/12$ which weighs .051 lb. per foot.

Double Butt

Plate Thick-ness in.	Gap in.	60° Butt			70° Butt		
		Area sq.in.	Vol. cu.in.	Wt. lb.	Area sq.in.	Vol. cu.in.	Wt. lb.
$\frac{3}{16}$	$\frac{1}{16}$	.075	.900	.255	.085	1.022	.289
$\frac{3}{16}$	$\frac{1}{8}$	.119	1.416	.401	.136	1.632	.462
$\frac{1}{4}$	$\frac{1}{8}$	.192	2.300	.651	.218	2.611	.735
$\frac{5}{16}$	$\frac{1}{8}$	.260	3.120	.883	.293	3.516	.995
$\frac{3}{8}$	$\frac{1}{8}$	.328	3.936	1.114	.380	4.560	1.291
$\frac{1}{2}$	$\frac{1}{8}$	.410	4.920	1.392	.477	5.722	1.619

Figures shown allow for $\frac{1}{2}$ in. thickness reinforcement both sides.

**COMPARATIVE HARDNESS SCALES AND MUREX
ELECTRODE DEPOSIT HARDNESSES**

V.P.N.	Brinell 3000 kg	Rockwell C Scale	Approx. U.T.S. Tons/sq. ins.	Murex Electrode Single Layer on Mild Steel
100	95	—	23.0	
120	115	—	27.5	
140	135	—	31.5	
160	155	—	36.0	Vodex
180	175	—	40.0	Fortrex 35
200	195	—	44.0	
220	215	—	47.5	Austex (as- deposited)
240	235	20.3	51.0	Hardex 250
260	255	24.0	55.0	
280	275	27.1	58.5	
300	295	29.8	63.0	
320	311	32.2	67.5	
340	328	34.4	72.0	Hardex 350
360	345	36.6	76.0	
380	360	38.8	80.5	
400	379	40.8	85.0	
420	397	42.7	89.0	Chromex 1, Hardex 450
440	415	44.5	93.5	
460	433	46.1	98.0	
480	452	47.7	103	
500	471	49.1	107	Hardex CHR
520	487	50.5	112	
540	507	51.7	116	
560	525	53.0	120	Austex (work hardened)
580	545	54.1	125	
600	564	55.2	129	
620	582	56.3	133	
640	601	57.3	138	
660	620	58.3	142	Hardex 650
680	638	59.2	147	
700	656	60.1	—	
720	670	61.0	—	
740	684	61.8	—	
760	698	62.5	—	
780	710	63.3	—	
800	722	64.0	—	Hardex 800
820	733	64.7	—	
840	745	65.3	—	
860	—	65.9	—	
880	—	66.4	—	

1 INCH = 25.399978 MILLIMETRES				1 MILLIMETRE = .03937013 INCH			
Inches	M./m.	Inches	M./m.	Inches	M./m.	Inches	M./m.
1/64	.0156	.3969	17/64	.2559	6.5	.5118	13
1/32	.0197	.5	27/64	.2656	6.7469	.5156	13.0969
3/64	.0313	.7937	9/32	.2756	7	.5313	13.4937
5/64	.0394	1	7/16	.2813	7.1437	.5315	13.5
7/64	.0469	1.1906	29/53	.2953	7.5	.5469	13.8906
1/16	.0591	1.5	19/64	.2969	7.5406	.5512	14
5/32	.0625	1.5875	5/16	.3125	7.9375	.5625	14.2875
1/8	.0781	1.9844	3150	.3150	8	.5709	14.5
3/32	.0787	2	21/64	.3281	8.3344	.5781	14.6844
7/32	.0938	2.3812	3346	.3346	8.5	.5906	15
1/4	.0984	2.5	11/32	.3438	8.7312	.5938	15.0812
5/16	.1094	2.7781	3543	.3543	9	.6094	15.4781
1/8	.1181	3	23/64	.3594	9.1281	.6102	15.5
3/16	.125	3.175	3740	.3740	9.5	.625	15.875
9/16	.1378	3.5	375	.375	9.5250	.6299	16
5/8	.1406	3.5719	25/64	.3906	9.9219	.6406	16.2719
11/16	.1563	3.9687	3937	.3937	10	.6496	16.5
13/16	.1575	4	13/32	.4063	10.3387	.6563	16.6687
15/16	.1719	4.3656	4134	.4134	10.5	.6693	17
17/16	.1772	4.5	27/64	.4219	10.7156	.6719	17.0656
19/16	.1875	4.7625	4331	.4331	11	.6875	17.4625
21/16	.1969	5	7/16	.4375	11.1125	.6890	17.5
23/16	.2031	5.1594	4528	.4528	11.5	.7031	17.8594
25/16	.2165	5.5	29/64	.4531	11.5094	.7087	18
27/16	.2188	5.5562	15/32	.4688	11.9062	.7188	18.2562
29/16	.2344	5.9531	4724	.4724	12	.7283	18.5
31/16	.2362	6	31/64	.4844	12.3031	.7344	18.6531
1/2	.25	6.35	1/2	.4921	12.5	.7480	19
				.5	12.7	.75	19.05

NOTES

NOTES

NOTES

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